CONCORDE

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G-BOAC. The ‘fineness ratio’ (length to diameter ratio) must be high to reduce ‘wave drag’ (caused by the formation of shock waves). Concorde’s elegance was due to aerodynamic necessity. (John Dibbs/aviation-images.com)

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A doctored publicity photo depicting how a formation of four BA Concordes would have appeared in their final livery. In reality Concorde never flew such a formation in these colours. (British Airways)

INTRODUCTION

Concorde 001 in its joint Aerospatiale/BAC livery.
(Photo by Rolls Press/Popperfoto/Getty Images)

The second half of the twentieth century witnessed one of the greatest breakthroughs in civil aviation since the Wright brothers – the conquering of flight at speeds faster than sound. The result was the most superlative form of transport yet built by man – Concorde, the only successful Super Sonic Transport, or SST. Conceived in 1962, and launched into commercial service in 1976 following 14 years of research and development, Concorde was hailed

as one of the great wonders of the technological world. Throughout 27 years of service she was to become an icon of speed and status.

THE PHOTO RECONNAISSANCE SPITFIRE

The theory of supersonic flight that would eventually be applied in the design of Concorde began its development during the Second World War. A number of Allied fighter pilots had experienced strange and dangerous effects when diving at speeds close to that of sound. To preserve frontline fighter pilots and to investigate flight at speeds close to Mach 1 (just below the speed of sound) – and to keep ahead of German advances in the new science – a series of high speed dives was arranged.

The aircraft chosen for these investigations was the Photo Reconnaissance Spitfire (PR Mark XI) fitted with the Merlin 61 engine. Such a Spitfire was capable of climbing to 40,000ft – high even by the standard of the subsonic jets of the 21st century. To achieve the highest speeds the power dive had to be started from as high as possible. Because of this and its relatively thin wings, the Spitfire PR Mark XI was considered a suitable aircraft for research into flight at transonic speed.

Some time in 1943, Squadron Leader Martindale, a test pilot for Rolls-Royce in civilian life, found himself in a 45 degree dive from 40,000ft. After 36 seconds from the start of the dive, descending through 29,000ft, the Spitfire attained Mach 0.9. From about Mach 0.75 upwards some of the airflow became compressed and therefore subject to different aerodynamic laws. The Spitfire experienced increased drag, loss of lift and a tendency to pitch further nose down. Uncorrected, the nose-down pitch would increase the dive angle. To prevent this, the pilot would pull the stick back to apply ‘up elevator’. At transonic speeds such action exposed the aircraft to another risk. Due to lack of stiffness in the tailplane and the great force of a compressed airstream on the up-going elevator, the leading edge of the tailplane could bend upwards, leaving the elevator trailing in the

slipstream. This resulted in the controls achieving the reverse effect of what was expected, namely pitching the aircraft further nose down. This effect is quite separate from the nose dropping due to the redistribution of the lift.

Entering the warmer atmosphere the Spitfire found itself in an environment where the speed of sound was greater. Although still travelling at roughly the same true airspeed, its speed with respect to the speed of sound (Mach number) was lower. The danger now was that the laws governing the airflow at the slower speeds would suddenly be restored. The 'up elevator' which had maintained the angle of descent could now, at the smaller Mach numbers, reassert itself with unnerving suddenness, pulling the aircraft out of the dive at such a rate that the wings might fold upwards, or flutter like a flag in a stiff breeze. There were no ejection seats in those days.

The Rolls-Royce Merlin 61 engine, which powered the PR XI, had been developed and fitted to the Spitfire Mark IX in response to a formidable new fighter fielded by the Germans in 1941: the Focke-Wulf 190. The increased performance of the Merlin 61 was largely due to the effectiveness of its supercharger. This added 70mph to the top speed and 10,000ft to the Spitfire's maximum altitude. In consequence it out-performed the Focke-Wulf 190.

The 'barrier' to greater speed from the Spitfire during its transonic dive was due to two effects. One was the large increase of drag it experienced as the compression waves built up at Mach 0.9; the other was the loss of thrust experienced by the propeller. The combined effect of aircraft forward speed and the turning speed of the propeller ensured that the outer portions of the propeller blades were travelling at supersonic speeds. At such speeds the propeller becomes very inefficient. Thus the Spitfire lost thrust just as its drag increased. A rocket-propelled, rather than a gravity-assisted, Spitfire might have been able to maintain Mach 0.9 for longer.

Rocket propulsion has the advantage over other kinds of propulsion in that the thrust it generates is not dependent on the forward speed of the aircraft. Nor is its thrust dependent on altitude; if anything it increases as the pressure of air around it decreases. Although rocket-propelled aircraft are spared the need for any kind of air intake, they

suffer the greater burden of having to carry extra fuel weight in the form of liquid oxygen (or some chemical suitable for combustion with the fuel). They therefore do not give propulsion suitable for sustained flight.

THE SUPERCHARGER

A supercharger is a device that compresses the air before it undergoes further compression in the cylinders of a piston engine. The supercharger on the Merlin 61 engine had been refined to near perfection by a brilliant young engineer at Rolls-Royce in Derby – Stanley Hooker. Hooker's work on superchargers was soon to have great relevance in the development of the jet engine, since the centrifugal compressors of the early jet engines were similar in principle to, although much larger than, the supercharger of the Merlin. The jet engine turned out to be the most suitable power plant for continuous supersonic flight. Eleven years after his work on the Merlin supercharger, Stanley Hooker began the transformation of the Bristol Olympus engine, destined, in its most outstanding version, to power Concorde.

JET-PROPELLED FLIGHT

The Gloster E28/39, Britain's first jet-propelled aircraft, which first flew on 14 May 1941. (Permission of Ian Whittle)

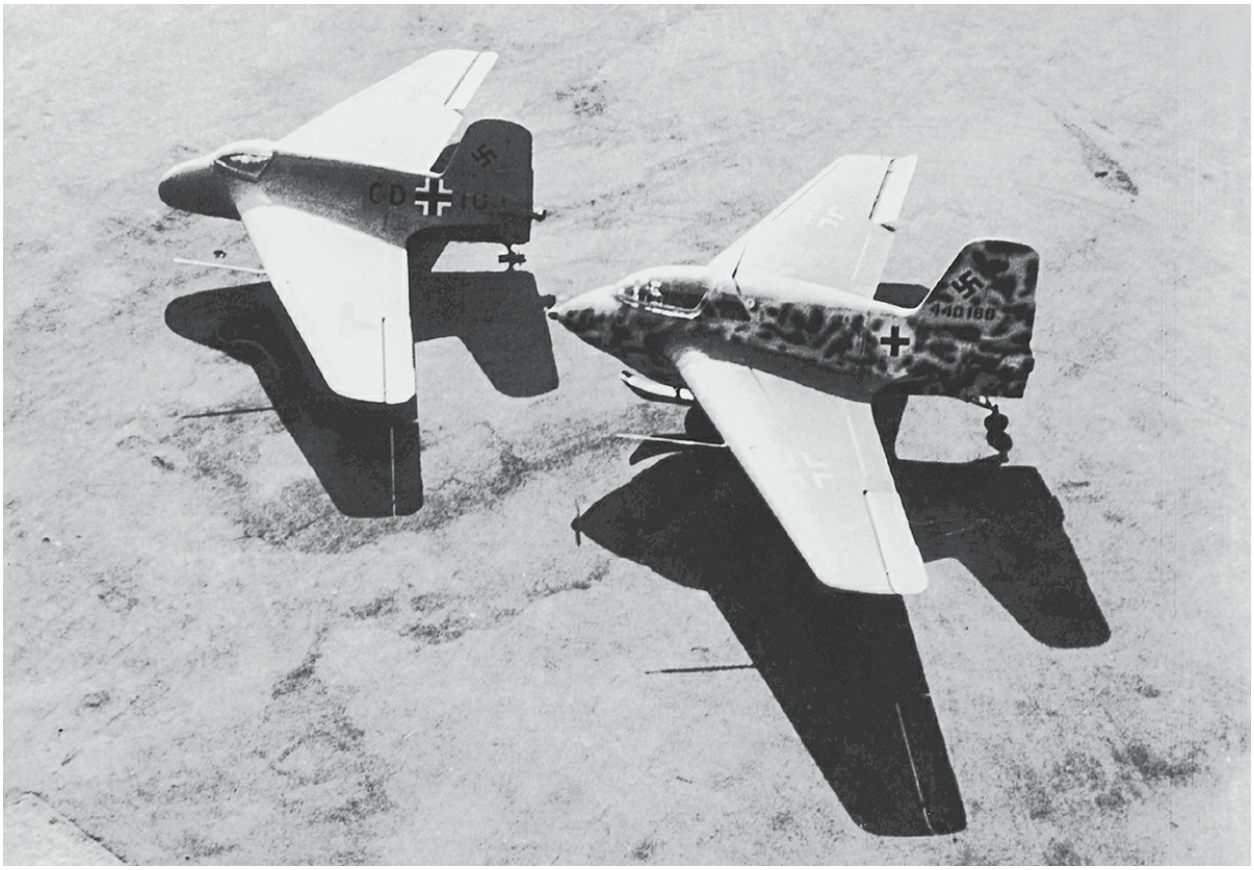
Happily, by 1943 there had appeared an engine which looked capable of giving sustained thrust both at subsonic and supersonic speeds. This was the jet engine. This new engine gave thrust, not through a propeller, but by virtue of its high speed jet efflux. The fact that its intake might be in a supersonic airflow would be, if anything, a bonus, since the incoming air could be slowed down and therefore 'supercharged' prior to entering the compressor on the engine, making the engine yet more efficient.

Jet-propelled flight had become a reality in Britain in 1941 with the first flight of the Gloster E28/39. Designed by Sir Frank Whittle, inventor of the jet engine principle, the Power Jets W2/700 was chosen, in 1943, as the power plant for Britain's first supersonic project: the Miles M52 (E24/43). It was hoped optimistically that the M52 would exceed 1,000mph (about Mach 1.5) in level flight. There was a great

deal of debate over the choice of wing section for the aircraft. Thin wings, suitable for supersonic flight, seemed to be the obvious choice, but their lack of efficiency at subsonic speeds meant that the aircraft would not be able to climb to such a high altitude as one fitted with conventional wings; the higher the altitude, the higher the Mach number that could be attained in the ensuing dive. Once comfortably supersonic, it was hoped that the aircraft could level off, maintaining speed – engine thrust having increased to cope with the higher drag associated with supersonic flight.

Soon it became evident that more research was needed to give sufficient thrust to the M52. The reason that the Ministry of Supply gave for the cancellation of the project in 1946, however, was that it was concerned for the safety of the jet's pilot. In 1948, a pilotless, rocket-propelled, scaled down version of the M52 did achieve about Mach 1.4, which proved that its planform with straight wings could cope with supersonic flight. However, at the end of the Second World War, British design was influenced by swept wings, which gave better performance at both supersonic and high subsonic speeds.

SWEPT WINGS



The Me 163 Komet, Germany's rocket-propelled interceptor. The aircraft on the left is a prototype, lacking the nose-mounted generator of the production aircraft on the right. (Courtesy EN Archive)

Before the outbreak of the Second World War, a German scientist, Professor Adolf Büsemann, had published findings suggesting that swept wings would perform better than straight wings in supersonic flight. One significant reason for this is that the shock waves generated at the nose of an aircraft miss the wing tips if these are swept back. Thus there is not the added complication of interference between wings and shock waves. Astonishingly these findings, freely available to all, went unnoticed.

Equally remarkable was the failure of the Allies to understand why the wings were swept on the rocket-propelled German fighter (the Messerschmitt Me 163 Komet). The Komet was a tailless, swept-winged interceptor, which was very fast, achieving Mach 0.8 (about 550mph) for short periods. The Allies believed that rocket propulsion and low

airframe drag could explain its high speed. The wings were swept sufficiently far aft to allow control in pitch (how much the aircraft is pointing up or down), and shaped outboard to render stability, which would cause a pitch up if the speed increased and vice-versa. There was no need for a heavy and draggy tailplane.

The Allies did not appreciate that swept wings increased an aircraft's 'critical' Mach number. This is the speed of the aircraft at which the airflow over the wing becomes supersonic, with the danger of causing severe control difficulties. According to Eric 'Winkle' Brown, who test flew a Me 163 Komet, 'It was rather like driving a run-away train'. Even in his mid-nineties his recall of the 487 different aircraft that he flew during his career was nothing short of astounding. He maintained that if the 'critical' Mach number of the Komet were exceeded, about Mach 0.84, it would have been precipitated into a 'graveyard' dive. Without sweep, the Komet's critical Mach number would have been Mach 0.70 or less.

The ratio of wing thickness to the distance travelled by the airflow over a wing (the aerodynamic chord) governs the critical Mach number. A low ratio is required when a higher critical Mach number is needed. To increase the critical Mach number, the wings must be made thinner or further swept back. Variable sweep in flight works on smallish military aircraft. Variable thinning was not an option. However, Boeing discovered while attempting to design a huge swing wing SST, that its weight meant that either passengers or hinges could be carried; but not both. On Concorde, where the wing attaches to the fuselage the chord length is over 90 feet (27.66m) giving a critical Mach number of about M 0.96. Its subsonic cruise speed was just below the transonic drag rise, M 0.95 – about 100 mph faster than most airliners, which are constrained to cruise at about M 0.82, or less if they are short haul.

Following the Spitfire dives, it was discovered that some of the airflow becomes supersonic over an aircraft even though that aircraft is travelling subsonically. It is the portion of the supersonic airflow which causes the drag rise.

Thick wings experience this transonic drag rise at lower Mach numbers than thin wings. Wings must support the weight of the aircraft and have within them some space to contain fuel. High speed aircraft

need both strength and as much space for fuel as possible. The conflict can be resolved by sweeping the wings either forward or back. Although the ratio of the thickness of the wing to the distance from leading to trailing edge remains constant, the sweepback makes this ratio 'appear' smaller to the airflow. Now the air is less disturbed by the passage of the aircraft, so the aircraft can fly faster before the compression waves start to apply their drag increase. The benefit of this discovery, made by Professor Albert Betz (a German aerodynamicist), has been applied to jet-propelled airliners, virtually all of which have swept back wings.

THE DH108

To research flight with a swept-winged aircraft, the de Havilland company modified a Vampire, a single engined, straight-winged fighter, with its tail and fin surfaces connected via twin booms to the wings. The booms and the tail surface were removed, swept back wings fitted, and a swept fin was placed over the rear end of the fuselage. It resembled the Komet in many outward respects. The DH108 was partly intended as a research aircraft for what became the Comet airliner. At that time the philosophy among several British aircraft manufacturers had been that it was desirable to perfect a 'flying wing' to reduce the aerodynamic drag and the extra weight caused by tailplane surfaces. Sadly, after the loss of several such aircraft to lack of control in pitch, this philosophy had to be abandoned.

'Flying wings', as tailless aircraft were dubbed, would have had to carry their payload within the wing. For people to stand inside the wing it would have had to have been at least 7ft thick. The wing span would have been huge to cope with such a thickness. Furthermore, without a tailplane there was no way of aerodynamically balancing wing flaps. Without flaps, either the landing speed would have had to have been very fast or the wing too big for efficient cruise. It would thus have been an uneconomic proposition – the de Havilland Comet had a tail!

In 1948 John Derry, Chief Test Pilot of de Havilland, became, more by accident than by design, the first pilot in Britain to exceed Mach 1, in a DH108 during a test flight investigating transonic flight. Whilst attempting to recover from a dive at Mach 0.97, his aeroplane exceeded

the vertical and probably achieved Mach 1.02. He was lucky to survive. Geoffrey de Havilland, son of the founder of the firm, had been killed in a DH108 almost exactly two years earlier, probably having experienced similar very severe oscillations in pitch.

By the early 1950s, data had been acquired which would make the next steps in supersonic flight slightly easier. The first aim then was to build a jet fighter capable of intercepting the mammoth Russian nuclear bombers which were under development, and were capable of cruising between 30,000 and 40,000ft at around Mach 0.8.

The fighter had to have an excellent rate of climb and at least double the bomber's speed for a successful interception long before the bomber could reach its target. The second aim was to build a supersonic bomber which, because of its speed, would itself be very difficult to intercept.

Long-range supersonic flight, however, was going to be much more difficult to achieve than the short duration dash required of an interceptor. But should a bomber become a reality then a transport derivative could follow; such was the pattern generally established over the first 50 years of aircraft development. However, as far as the development of an SST was concerned, the introduction of missiles capable of intercepting supersonic bombers even at high altitude was to upset this evolutionary pattern. The SST would have to be developed almost in its own right.

The de Havilland Comet 1 represented Britain's great leap forward in the post-war aviation era. (Photo by Fox Photos/Getty Images)

CHRONOLOGY

Concorde 002 rolls out of the assembly line at Filton, Bristol on 12 September 1968. (Photo by Central Press/Getty Images)

1956

5 Nov Supersonic Transport Aircraft Committee (STAC) established.

1959

9 Mar STAC recommends design studies of two supersonic airliners.

1961

June–July First Anglo-French discussions on possible SST collaboration.

1962

29 Nov Anglo-French agreement for joint design, development and

manufacture of a supersonic airliner.

1963
Spring Preliminary design presented to airlines.
13 Jan President de Gaulle uses name 'Concorde'.
June Concorde sales option issued by Pan American Airlines. BOAC (British Overseas Airways Corporation) and Air France sign Concorde sales options.
5 June US SST programme announced.

1964
Spring Announcement that development of a medium-range SST had been abandoned to concentrate on just one enlarged version.

1967
11 Dec Prototype 001 rolled out at Toulouse. British partner adopts 'Concorde' spelling.

1968
Feb UK government announces £125 million loan for Concorde production.

1969
2 Mar First flight of 001, Toulouse.
9 April First flight of prototype 002, Filton.

1971
24 Mar Congress stops US SST programme.
17 Dec First flight of first pre-production Concorde, 101, Filton.

1973
10 Jan First flight of Concorde 102, Toulouse.
Sept 102 leaves Paris for first US visit and breaks Washington–Paris record (3hrs 33mins) on return flight.
6 Dec First flight of 201, first production Concorde.

1975

9 Oct Concorde receives French Certificate of Airworthiness (C of A).
14 Oct British Airways and Air France open reservations for Concorde scheduled services.
5 Dec Concorde receives British C of A.

1976

21 Jan Airline service begins, London–Bahrain (BA, 206) and Paris–Rio via Dakar (AF, 205).
4 Feb Concorde services to New York and Washington for 16-month trial period approved by US Secretary of Transportation. Concorde was still banned at JFK by The Port of New York Authority.
24 May Transatlantic flights to Washington begin, from both Paris and London.

1977

22 Nov Services to New York begin, from Paris and London.
9 Dec Service from London to Singapore via Bahrain begins.

1979

9 Jan US type certificate awarded.
12 Jan Braniff subsonic service between Washington and Dallas/Fort Worth inaugurated.
22 Feb British Government announces BA to write off Concorde purchase cost: Government to receive 80% of operating surpluses.
16 Dec BA Concorde flies London–New York in 2hrs 59mins 36secs.

1980

1 June Braniff ceases Dallas/Fort Worth service.
1 Nov Singapore services discontinued.

1981

14 April Report on Concorde published by Commons Industry and Trade Committee expresses dissatisfaction with cost figures.
11 Sept British and French governments commission study on future of Concorde.

1982

1 May Formation of Concorde Division within BA, responsible for profitability of Concorde operations.

1983

1 Jan Fastest transatlantic crossing west-to-east, New York–London in 2hrs 56mins.

1984

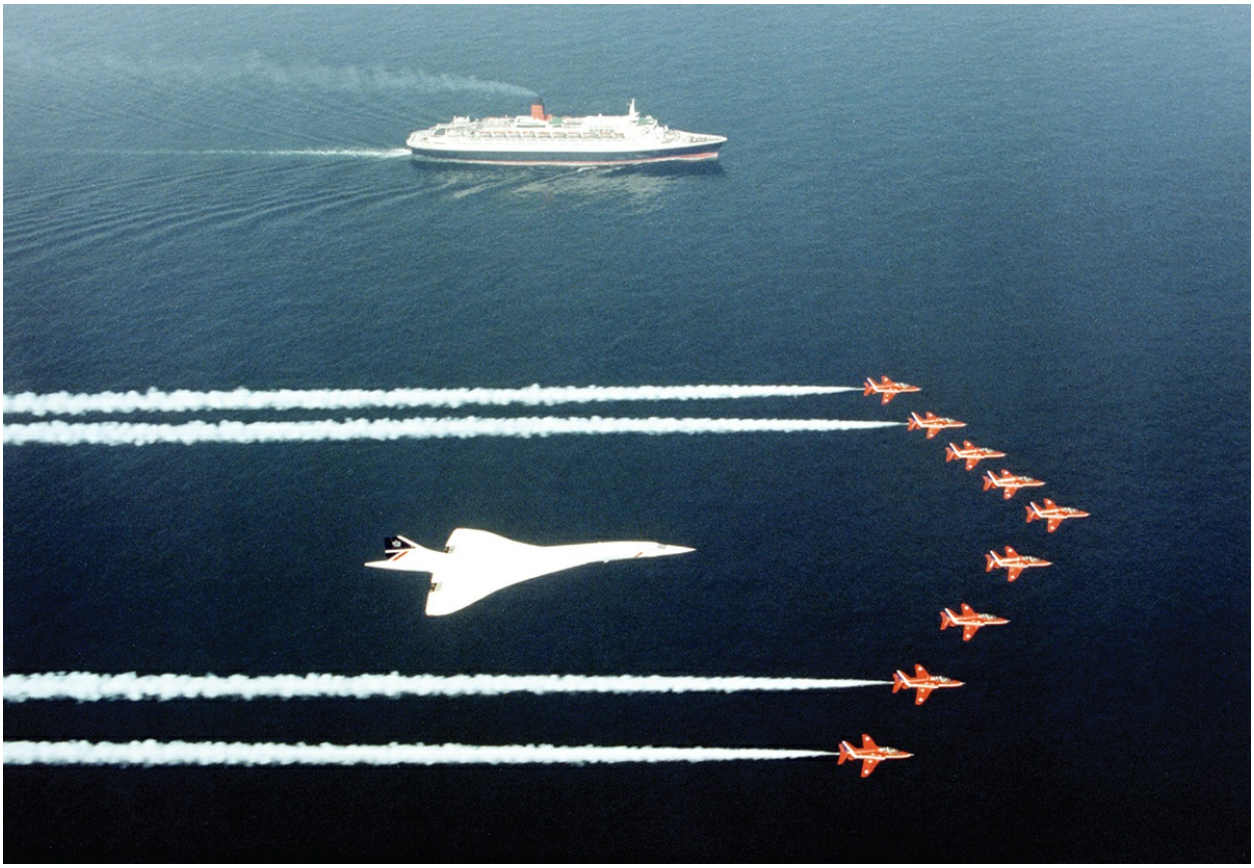
27 Mar Concorde's inaugural flight to Miami via Washington.

31 Mar The British Government's involvement in the Concorde project becomes minimal. BA becomes responsible for funding Concorde's British manufacturers.

1985

13 Feb First commercial service London–Sydney by Concorde under charter, establishing a record time of 17hrs 3mins.

19 Dec Highest recorded ground speed by Concorde to date, achieved by G-BOAC in commercial service, 1,292kts (1,488mph).



The three icons, Concorde G-BOAG, the Red Arrows and the QE2 over the English Channel, summer 1985. (British Airways)

1986

21 Jan Concorde celebrates 10 years of commercial operations.
8–23 Nov Concorde's first round-the-world charter.

1987

6 Sept Captain Brian Walpole sets new transatlantic speed record – just 95mins between Hopedale, Newfoundland, and the north-west Irish coast.
22 Nov Concorde celebrates tenth anniversary of operations into New York JFK.

1990

14 April Captain Norman Britton takes New York–London record with 2hr 54min 30secs flight.

1 June Concorde flies Honolulu–Hong Kong in 6hrs 30mins (subsonic time 13hrs 10mins).

1993

26 Mar Senior First Officer Barbara Harmer of BA becomes first female Concorde pilot.

21 May Concorde G-BOAF to become first of seven to have £1m refurbishment.

1994

7 Jan Concorde BA 001 Heathrow–New York first flight with new cabin crew uniform.

Oct Concorde ceases services to Washington.

1996

Jan Collision avoidance radar, essential for flight over USA, fitted successfully to Concorde.

7 Feb Captain Leslie Scott breaks New York–London record, with a 2hr 52min 59sec flight.

1997

28 May BA Concorde fares up 15% to £5,596 LHR–JFK return, passenger numbers unaffected thanks to soaring UK economy. AF Concorde fares up only 8%.

2000

25 July AF Concorde 203 crashes near Paris CDG, 114 souls killed. BA and AF suspend Concorde flights.

26 July BA resume Concorde flights; AF states: no resumption until cause has been established. Investigations begin.

Aug BA grounds its Concorde fleet. DGAC and CAA withdraw Concorde's C of A.

2001

5 Sept Concorde's C of A restored.

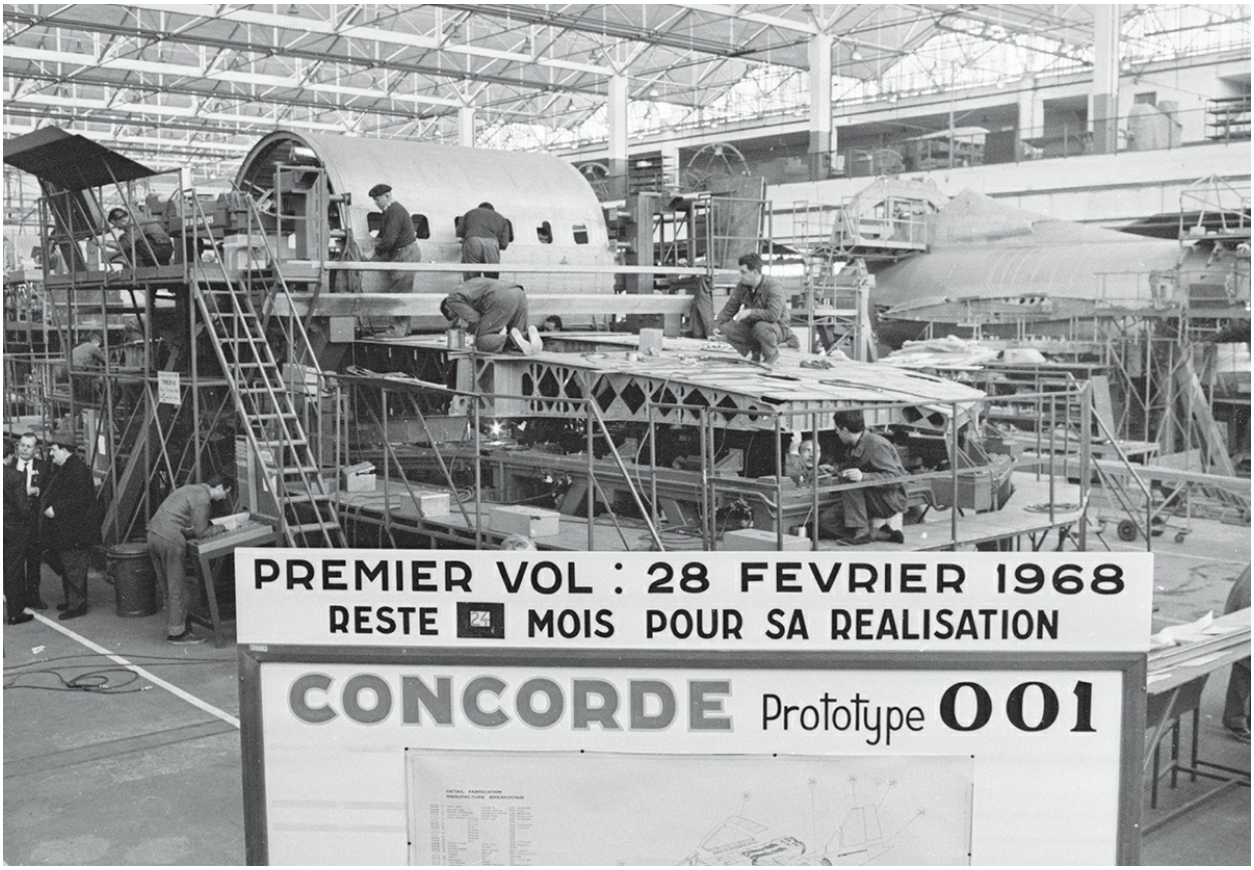
7 Nov BA and AF resume services to New York.

2003

10 April World airline revenue falls. BA announces cessation of Concorde operation as of 31 October 2003 and AF as of 31 May 2003.
27 June Concorde F-BVFC arrives at Toulouse, the final flight of the French Concordes.
24 Oct Crowds jam Heathrow to greet final three Concorde landings.
26 Nov Concorde G-BOAF final flight LHR to Filton supersonic over Bay of Biscay.

On 26 November 2003, Concorde is welcomed to her birthplace on her final flight to Filton. (SWNS)

DESIGN AND DEVELOPMENT



The Concorde prototype 001 under construction at the Sud Aviation factory. (Photo by J Wilds/Getty Images)

Prompted by the proliferation of designs for supersonic interceptor aircraft that appeared in the 1950s, people began to wonder whether a civil supersonic transport could be a possibility. It would take almost a decade of research and development, but by 1962, the idea of building an SST appeared to be worth pursuing.

The work began in 1954, when Sir Arnold Hall, then director of the Royal Aircraft Establishment (RAE) Farnborough, asked Morien

Morgan, involved with the Advanced Fighter Project Group and a great proponent for civil supersonic flight, to chair a committee to look into the feasibility of building an SST. The reported findings suggested it might just be possible to fly 15 passengers from London to New York at Mach 2 in an aircraft with an 'all up weight' (maximum take-off weight including the passengers and fuel) of 300,000lb (136,000kg). For comparison Concorde carried 100 passengers (up to 128 with reduced space between seat rows) over that range with an all up weight of 408,000lb (185,000kg). The envisaged 15-seater SST was based on the design of the Avro 730 supersonic bomber project that was cancelled in 1957. It had thin, unswept wings, with engines mounted on the wing tips. But for an SST to be economically viable, a better aerodynamic shape would have to be devised.

Such a shape did appear with dramatic impact, in the form of the British Fairey Delta 2.

THE FAIREY DELTA 2 AND THE ENGLISH ELECTRIC P1

On 10 March 1956 Peter Twiss (Chief Test Pilot of Fairey Aviation) exceeded the previous world airspeed record, held by the American Colonel Haynes in an F-100 Super Sabre, by 310mph. A reheated Rolls-Royce Avon RA5 turbojet propelled the FD2 at the astonishing speed of 1,132mph (Mach 1.7).

In November 1956 the Supersonic Transport Aircraft Committee (STAC) was formed, chaired by Morien Morgan. Hearing evidence from 17 interested bodies, representing the aircraft industry, airlines and ministries, its conclusions were reported in 1959. The result was Concorde, which made its maiden flight ten years later.

Contributors to its success were the FD2 and the English Electric P1 (the prototype Lightning fighter), both offsprings of Morgan's Advanced Fighter Project Group which had been formed in 1948. The success of these two aircraft banished the notion of some kind of intractable barrier at Mach 1, the speed of sound. It is interesting to look at the different design philosophies.

Both designers produced a different planform: the P1 with swept

wings and a tailplane, while the FD2 a delta wing without a tail. Tailless designs had encountered many problems, as exemplified by the DH108. Therefore English Electric wanted to ensure stability and control through use of a tail surface, especially for flight in the tricky transonic range. Fairey believed, however, that a 60 degree delta with powerful trailing edge control surfaces would provide a stable aircraft throughout this range. After all, experience had shown that tail surfaces were a major source of aerodynamic buffet at transonic speeds – why run this risk by having a tail at all?

As it turned out, both designs were supremely successful. In different ways both contributed to Concorde's eventual success: the FD2, because it was converted into the modified delta shape that was to be applied to Concorde; the P1, because a great deal was learned about the variable exhaust nozzle on the Rolls-Royce Avon engine, a necessary device for the efficient use of a variable thrust reheat system. It is the variable exhaust nozzle system on the Olympus engine, as fitted to Concorde, which eked out every last remaining ounce of thrust and fuel economy from the jet efflux both with and without reheat.

The FD2 in flight. Fairey believed that the delta wing with no tailplane was the optimum solution for a supersonic aircraft. (COPYRIGHT BAE SYSTEMS)

REHEAT

'Reheat', or 'afterburner' as it is known in the United States, is a device which can be fitted to the rear of the main jet engine, within the exhaust duct, to give an extra 'push' to the aircraft. It consists of a ring of nozzles which spray fuel to be burned in the engine exhaust gases, which still have sufficient oxygen to support combustion, prior to its leaving through the exhaust nozzle. As the velocity of the jet gases are so much greater with reheat on, the exhaust nozzle must vary in area to accommodate two situations. On the FD2 the reheat was either on or off, thus the exhaust nozzle only had the two positions – open or wide open. On the P1 the reheat was variable so the exhaust nozzle had to be variable as well. On the Olympus 593, as fitted to Concorde, not only is there a variable nozzle to accommodate the reheat, but there is a secondary nozzle which, amongst other things, forms a divergent duct for efficiency during the supersonic cruise. Furthermore the primary nozzle area varies continually, even without reheat, thus keeping the Olympus engine constantly in tune.

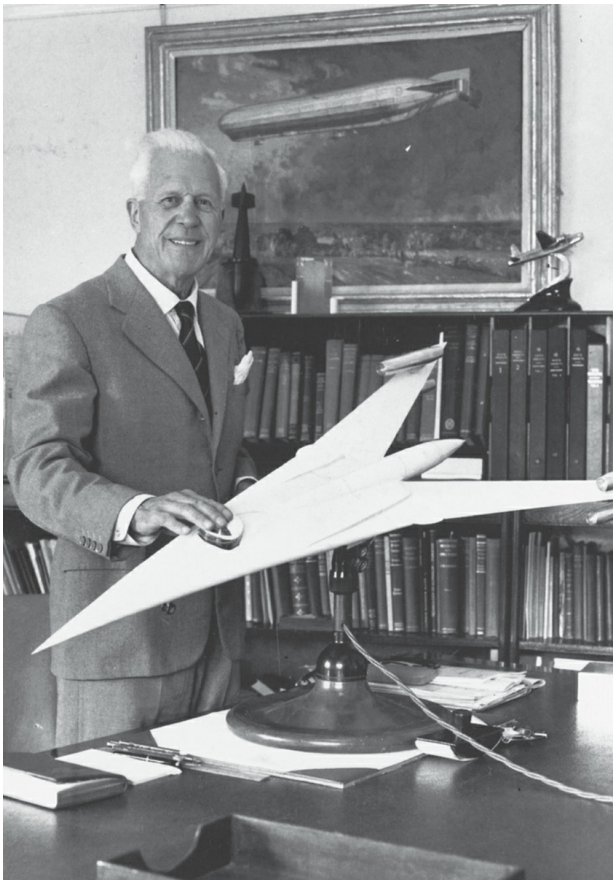
THE FORMATIVE PHASE

The STAC met regularly from November 1956 until March 1959. Among its recommendations was one which strongly favoured building a long-range SST to carry 150 passengers from London to New York non-stop with a cruising speed of not less than Mach 1.8. The committee regarded cruising speeds approaching Mach 3 as feasible, but technically difficult. At Mach 3 the highest temperature experienced by the fuselage is around 335°C (635°F); thus not only is it much more difficult to keep the occupants cool, but the skin has to be made from the more expensive alloys of titanium and perhaps even from stainless steel. The cheaper and well tested aluminium alloy, although highly satisfactory at temperatures up to 130°C (266°F), does not cope with temperatures of over 300°C (572°F) at all. A Mach 3 version was regarded as a possible second generation SST. There was also a recommendation for the construction of a shorter-range SST to cruise at Mach 1.2.

Between London and New York a cruising speed of Mach 3, compared to Mach 2, would reduce the total journey time by about 40 minutes, about 20%. The real gain of a Mach 2 airliner was that it could more than double the speed of the current subsonic airliners, which were designed to cruise at just above Mach 0.8. Any economic gains associated with the yet quicker journey times made possible at a speed of Mach 3 would be more than wiped out by the fact that a Mach 3 SST would cost disproportionately more to build. Following the recommendations of the STAC, feasibility studies were commissioned by the Ministry of Defence, then headed by Duncan Sandys. Bristol produced studies of an SST with a conventional fuselage and slender delta wings, but Hawker Siddeley provided a study for an integral layout – a slender delta with a longitudinal swelling in which would be housed the passengers – virtually a slender delta flying wing.

Among other designs which were also put forward at about this time was the Swallow designed by Sir Barnes Wallis, an aircraft in which variable sweep had been taken to the extreme. The engines, mounted outboard on the wings, were pivoted and could be used for stability and

control in place of aerodynamic surfaces. Furthermore, their movement with the wing sweep contributed to the balance of the aircraft. Aerodynamic balance was maintained on Concorde by moving the fuel to change the centre of gravity.



Sir Barnes Wallis with a model of Swallow. In the background are examples of his earlier engineering efforts including bombs, airships and the Wellington bomber. (COPYRIGHT BAE SYSTEMS)

An ‘arrow’ planform is attractive because it is very efficient aerodynamically at supersonic speeds. The ability to vary the sweep of the wings (variable geometry) could maximise this advantage. In the unswept configuration, the engines on the Swallow were well outboard of the centre line. Following an engine failure, there might have been a difficulty in keeping directional control; especially as there was no fin or rudder. A ‘laterally’ thought out way of how to achieve variable geometry in flight is to ‘slew’ a single wing in its entirety. The wing could either be mounted on a conventional fuselage or, as studied by

Handley Page (HP), without. In 1961 HP proposed an SST carrying its payload of 150 passengers within the wing. The slew would be varied according to Mach number. Effectively the passengers would be facing in the direction of flight at low speed then sideways during the supersonic cruise. Without digital computers the flight control laws might have been impossible to apply. Even had it worked, marketing an aircraft which lacked the elegance of symmetry could have proved wearisome, not helped by it being called a slew wing.

A third proposal envisaged a slender delta with a large number of lifting engines to give it a vertical take-off capability. No fewer than 50 such engines were thought to be necessary on a transatlantic SST! The rate of fuel burn of the lifting engines was expected to be very high – and the result of them all failing to start simultaneously prior to landing would have left the aircraft in a somewhat perilous state.

These three proposals failed to exploit the discovery that extra lift could be obtained by allowing the airflow to separate over the upper surface of a slender delta wing. To give lift, under normal circumstances, the flow of air over a wing must not separate from the wing. The airflow travels slightly further over the top surface than under the bottom surface and so has to move more quickly over the top than the bottom. As it accelerates, its pressure drops. In this way the wing is 'sucked' upwards, rendering lift to it and to whatever the wing is attached. Should this airflow become turbulent, thus breaking away from its ordered flow, the lift will suddenly reduce; the wing is then said to 'stall'. At the tip of a wing in normal flight is a small vortex – a whirlpool of air rotating, in this case, about a horizontal axis; it is caused by the higher pressure air underneath twisting into the lower pressure air on top. Such a vortex, on a larger scale, can be harnessed to give lift to a slender delta wing in slow speed flight; high lift devices (flaps and slats) then are not necessary.

A big contribution in the study of flow separation was made by EC Maskell of RAE. He and Dr Dietrich Küchemann, head of Aerodynamics at RAE, laid the foundation of this new technique. The slender delta was performing well in the transonic and supersonic regimes, could it also perform at low speeds? A practical test was needed to prove both that the theory was correct and that no dangerous

side effects would prevent it being applied to an SST.

THE HP 115

Consequently the feasibility programme that was commissioned following the final report from the STAC included a contract to Handley Page to build an aircraft to test what the flying paper darts, beloved by schoolboys, had suggested: that vortex lift could give sufficiently stable lift to allow a slender delta flying at low speed to be controllable.

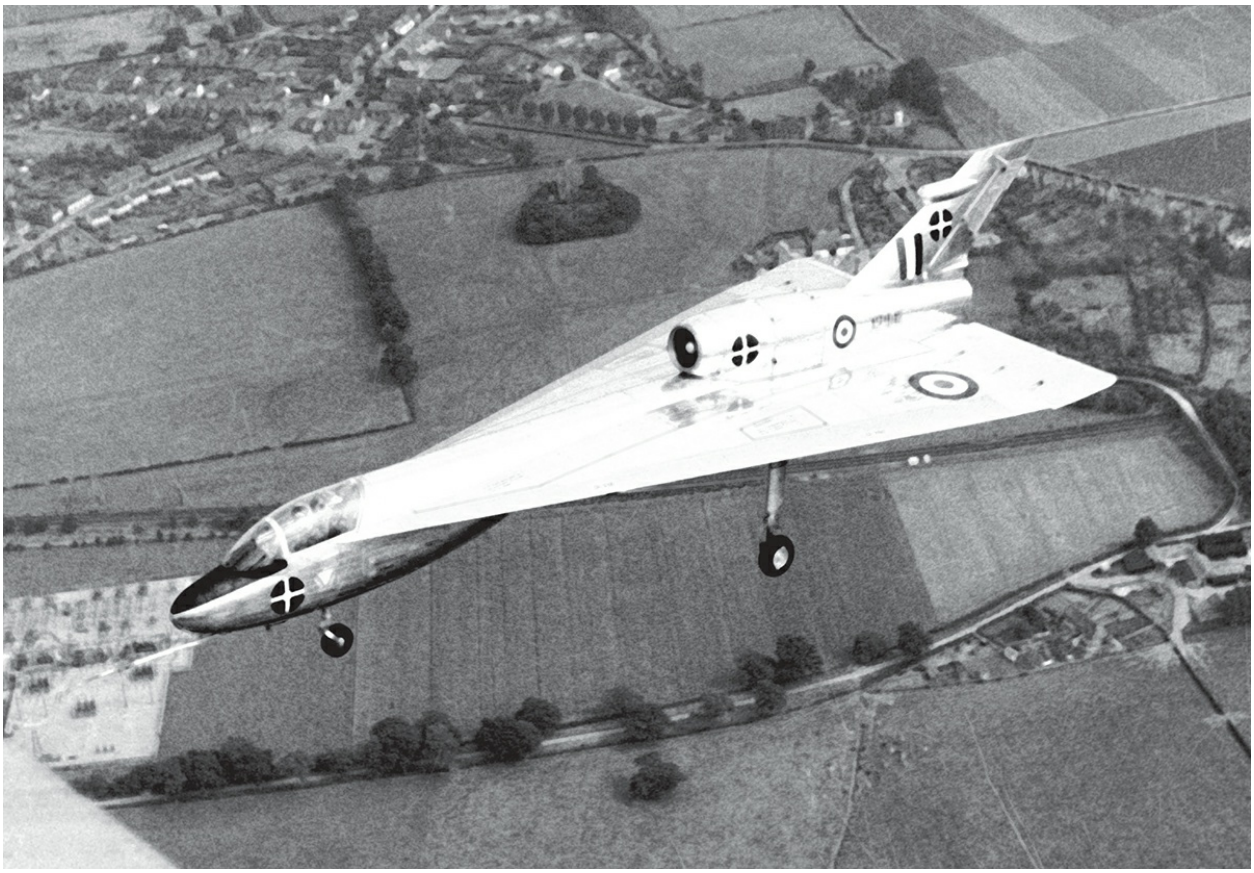
The resulting aircraft was the experimental Handley Page 115. It was powered by a single Viper jet engine. Although its 76 degree swept wings gave the illusion that it was built for great speed, it was designed purely to explore flight at low speeds – it did not even have a retractable undercarriage.

The handling of the HP 115 was better than anyone had dared to hope. It gave excellent lift at slow speed. Even landing in a cross-wind, a situation which might have caused difficulty, was trouble-free.

Success with the HP 115 proved that the resulting SST would not have to be complicated with flaps and slats to enable its wing to give sufficient lift at take-off and landing speeds. If it had one small vice it was that as the speed became slower the drag caused by the wings giving lift became greater. Although this obviates the need for air-brakes, the extra drag has to be overcome by increasing the thrust. Provided there is plenty of thrust available, all is well; but the danger lay in the pilot not spotting the speed loss and thus not applying the extra thrust required by the lower speed. Without proper monitoring of the speed, it could fall off to the point, not of the wings being unable to give lift and so stalling, but to the point where there was not enough thrust to overcome the extra drag associated with the low speed. To overcome this problem it was recognised that such an aircraft would have to be fitted with an automatic throttle. Indeed on Concorde there was just such a device and it worked extremely well too.

Although the slender delta promised to have a better lift to drag ratio (L/D) at supersonic speeds than other planforms, the unpalatable fact remained that there is a drag rise as Mach 1 is approached. In fact the

L/D dropped, on Concorde, from about 12 at Mach 0.95 to 7.5 at Mach 2. How then was the future SST going to have enough range to cross the Atlantic?



The HP 115 in flight. First flown in August 1961, its success paved the way for Concorde. (Photo by SSPL/Getty Images)

Happily, jet-engine efficiency can be designed to improve with speed, more than compensating for the loss of aerodynamic efficiency. The projected SST was expected therefore to travel further (or at least as far) on a gallon of fuel at its supersonic cruising speed as it could at its subsonic cruising speed, Mach 0.95. This fortunate state of affairs is brought about because the efficiency of the turbojet engine is very much enhanced if the air is pre-compressed prior to engine entry. At speeds in excess of Mach 1.4, sufficient pre-compression can be arranged to occur inside the intake system where the air is slowed – hence compressed – to about half the speed of sound before it reaches the engine. Nobody doubted that the intake system would need some kind of variable

'throat' so that it could cope efficiently with various speeds and especially those in excess of Mach 1.5. Since engine efficiency improves with speed up to Mach 3, there was a great incentive to go as fast as the kinetic heating of the structure would allow – Mach 2.2 appeared the most attractive speed if a well-tried and tested aluminium alloy was used.

However, Mach 2.04, which reduced the maximum temperature from 156°C to 127°C (313°F to 261°F), was ultimately chosen since the lower temperature gave less of a problem with the oil and fuel.

By the late 1950s, it was realised, tantalisingly, that aerodynamic and thermodynamic development had progressed far enough to allow an SST to become a reality. The question now became: would disappointments with the performance of British civil aviation spur government and industry into turning the theory of a paper dart into a practical SST?

THE DE HAVILLAND COMET

British civil aviation in the years after the Second World War had hoped to equal or better anything the Americans could produce. On 15 May 1952 the era of the passenger jet was opened when a de Havilland Comet 1 set off for Johannesburg from Heathrow. To extol the virtue of vibration-free flight, a picture was published of a coin balanced vertically on its rim on a table in the cabin of a Comet 1 whilst in the cruise at an altitude in excess of 30,000ft. The days of the piston propeller-driven airliner were numbered. This 'number' would have been even smaller had disaster not struck the Comet 1. Following a searching investigation, the reason for the tragic loss of two Comet 1 airliners in early 1954 was revealed. Cracks originating in the corner of a window in the pressurised fuselage for a radio navigation aerial had propagated so quickly that the cabin shell had just exploded. There followed an intense period of redesign. In October 1958, two weeks before the Boeing 707, the Comet 4 inaugurated the first transatlantic jet passenger service. The windows on the latest Comet had rounded corners; but notably the US aircraft industry became privy to the lessons too, the same expensive mistake would not be made over there. The

world lead in airliner manufacture, so nearly won by the Comet, had been lost. Would that lead, aeronautical sages wondered, be restored if an airliner capable of another halving of flight times were built?

THE VICKERS VC10

In the meantime, the British civil airliner programme was in a muddle. It had been galling for Sir George Edwards, Chairman of Vickers, that in 1956 the British Government had allowed BOAC (British Overseas Airways Corporation) to purchase the Boeing 707 from America. In the previous year, BOAC and the RAF had turned down the British equivalent to the 707 – the Vickers VC7 (V-1000 in its military form). Based on the Vickers Valiant bomber, it had engines buried in the inboard section of the wing with intakes at the wing roots. The VC7 was scrapped, to be supplanted by the Vickers VC10.

The Vickers VC10, with its 'clean' wing and four rear-mounted engines, was originally conceived as an airliner capable of operating from high-altitude airfields on hot days over the old 'Empire Routes'. Later its range was increased to compete with the Boeing 707. Although it was beloved by passengers as soon as it appeared in 1962, it was too late to sell in large numbers – the Boeing 707 had got in first. It typified the frightful divergence in the relationship between the British Government, the nationalised carriers (BOAC and BEA) and the aircraft industry. The Government, according to Sir Basil Smallpeice (Managing Director of BOAC from 1956 to 1963), had expected BOAC to support the British aircraft industry by buying British aircraft it did not want and then having to bear some of the financial burden incurred during the final stages of the development of the new aircraft. At the same time BOAC was expected to pay the Government a fixed rate of interest on the capital borrowed. Thus BOAC regarded the VC10 with a great deal of caution, fearing that the Government would force them to have a large number of VC10s they simply did not want. In the end some kind of compromise was reached, but not without acrimony.

Forewarned is forearmed. Sir Basil Smallpeice and Sir Matthew Slattery of BOAC made it clear to the Government in 1960 that although they would be delighted to assist with any future SST, this

would be at no financial risk to the airline and no orders would be placed unless the SST made economic sense. In the end the Government agreed to underwrite that risk.

It is true that there had been one British success – the short-haul Vickers Viscount, with sales exceeding 400. However, by the late 1950s and early 1960s, in the words of Sir Stanley Hooker, 'We've lost in the civil market to the Americans. Now these Boeing 707s and DC8s cannot possibly last for more than about ten years. Therefore in order to collar our fair share we must look towards building a supersonic airliner with a European partner.'

PARTNERSHIP WITH FRANCE

Concorde in flight, 1972. (Photo by Helmut Fleischer/ullstein bild/Getty Images)

By 1961, Britain had convinced herself that it was both highly desirable and technically possible to build an Atlantic-range (3,700 statute miles)

SST. There was one piece of the jigsaw missing, however: could a suitable partner be found to share the large cost of such a project? The right choice of partner, it was hoped, would lead not only to a successful SST but to co-operation in a host of other fields. A European partner, for instance, might pave the way for Britain's entry into the Common Market. At that time Russia and America were pouring millions into the exploration of space, without, apart from technical advance, any prospect of financial return. An SST promised technical advance and a financial return, the latter largely on the grounds that speed had always attracted customers.

Partnership with an American company was considered. But the Americans were more interested in Mach 3 designs, which had been ruled out by the British designers on account of the kinetic heating problem.

The only European country with the ability to undertake such a project in the early 1960s was France. The nation had to rebuild its once proud aircraft industry from the ashes of the Second World War. It was, in 1960, one of the few nations – with Russia, the United States, Sweden, Britain and Canada – to have designed, built and tested supersonic aircraft.

Starting with the straight-winged Trident, first flown in 1953, France had built a series of supersonic research aircraft. Most spectacular of the French research aircraft was the Nord Griffon. It had a propulsion unit which consisted of a turbojet within a huge outer casing. This outer casing formed a ramjet. The turbojet engine was used for slow speed flight and for starting the ramjet. The Griffon achieved Mach 1.85 (about 1,216mph) in 1957.

On the civil side the French had some success with the subsonic twin-engined Sud-Est Caravelle airliner. Its nose section was in fact the same as the British de Havilland Comet's. There was a lot of collaboration. Incidentally Concorde was to inherit, via this lineage, the triple hydraulic system labelled blue, green and, as a backup, yellow, which was originally fitted to the Comet.

Concurrent with the Nord Griffon were the swept-winged Mystères and the delta-winged Mirage fighters. The next logical step for Sud Aviation, as it had become by 1961, was to investigate the possibility of

building an SST. Sud Aviation had been formed from Sud-Est, run by Georges Hereil, the original proposer of the Caravelle, and Sud-Ouest.

Accordingly, at the Paris Air Show of June 1961 there appeared a model of a slender delta SST called the Super Caravelle. Although never built, it was designed to carry a payload of 70 passengers over 2,000 miles.

THE QUESTION OF RANGE

The Super Caravelle was thus not to have transatlantic range. In fact there was to be some wrangling between the British and French over decisions on range. The British, in spite of a mild flirtation with an 'M-winged' medium-range Mach 1.2 aircraft, had never considered it worthwhile to build anything with less range than London (or Paris) to New York. The Super Caravelle bore a remarkable resemblance to the BAC 223, the latest proposal from Archibald Russell, Technical Director of Bristol Aircraft which, by late 1961, had become part of the British Aircraft Corporation (BAC). Included in the merger were Bristol Aeroplane Co Ltd, English Electric Aviation Ltd, builders of the P1 Lightning, Hunting Aircraft Ltd and Vickers-Armstrong (Aircraft) Ltd, builders of the VC10.

The BAC 223 study had followed a proposal for a larger version – the Bristol Type 198, which had been considered too ambitious to gain Ministry approval.

The Type 198 design had been originally submitted as one of the feasibility studies which had followed the recommendations of the STAC. With transatlantic range at a cruise speed of Mach 2.2, it was to have had six Olympus engines in a bank on top of the wing under the fin. The projected all up weight was to be 385,000lb, with a passenger load of 132. Concorde turned out to be only 4% heavier with a similar load carrying ability and four Olympus engines of increased thrust instead of the original six.

The BAC 223 on the other hand, although still with transatlantic range, had a proposed weight of 270,000lb and was to be powered by four under-wing mounted Olympus engines. This question of size as well as range was already causing much controversy. A great deal of

unnecessary expense was incurred building tools and jigs for designs that were not produced.

Air France Concorde, photographed in December 1975. (STF/AFP/Getty Images)

Duncan Sandys, Secretary of State for the Colonies and Commonwealth Relatons, perceiving the political and economic advantages of collaboration between France and Britain, had encouraged Sir George Edwards, Chairman of the new BAC, to explore the possibilities of co-operation with Georges Hereil of Sud Aviation. At first, there did not appear to be much of a basis for co-operation due to the differing range philosophies. So discussions centred around collaboration on a common engine, on systems, electrics and hydraulics. There was only one engine that could sensibly be used for both the medium- and long-haul SST: the Bristol-Siddeley Olympus.

Bristol Aero Engines had persevered privately with the Olympus in spite of Government policy which had decreed, in 1957, that there would be just the one large engine programme, centred on the Rolls-

Royce Conway engine. Had it not been for the wisdom and foresight of Sir Reginald Verdon-Smith, Chairman of the Bristol Aeroplane Company, there would have been no engine immediately available and suitable for an SST.

There followed more meetings between the respective ministers to encourage collaboration. There was little result at first, other than the making of a few conciliatory gestures – the building of the tail section of the Super VC10 was subcontracted out to a Sud Aviation subsidiary.

FORMING AN AGREEMENT

In 1962 de Gaulle came to power in France. General André Puget replaced Georges Hereil, while in Britain Julian Amery became the Minister of Aviation. These changes propelled the two countries into an agreement with one another. De Gaulle saw this as a way of improving the French aircraft industry while Puget, unlike Hereil, was on the same wavelength as George Edwards; Amery was to seal this concord with an unbreakable treaty.

Just before the signing of the treaty, the Americans became perturbed by the progress being made in the field of SSTs in Europe. Accordingly, Eugene Black, ex-Chairman of the World Bank and a prominent and influential individual in the US corridors of power, attempted to dissuade Julian Amery from continuing with his plans. The Americans were afraid that Britain's gamble was going to pay off. It turned out that Eugene Black was about to become Chairman of a high-powered committee set up to study the possibility of the United States building an SST.

On 29 November 1962 an agreement between the governments of France and Britain was signed and registered in The Hague. The agreement comprised seven articles. It included clauses about each country having equal responsibility for the project, bearing equal shares of the cost and sharing equally the proceeds of sales. Two aircraft – a long-range and a medium-range one – were envisaged. Every effort was to be made to carry out this programme with equal attention to both the medium and long-range versions. There were to be two integrated organisations taken from British and French firms – BAC and Sud

Aviation for the airframe, Bristol Siddeley and SNECMA for the engine – which were to make detailed proposals for carrying out the programme. There was no break clause.

It was the first time in history that such a collaborative organisation had been set up.

The bureaucratic machinery that was to control the project stipulated that every decision was minutely and critically examined by both partners. This resulted in the project taking twice as long, and costing twice as much as it might have done had one partner had design leadership. Nevertheless the outcome, Concorde, was an astonishing technical achievement. It had the admiration of the world, though as it turned out, it was not to have the world as its customer.

Concorde G-BOAB flypast at Farnborough. (Photo by Richard Baker/In Pictures Ltd./Corbis/Getty Images)

TECHNICAL SPECIFICATIONS

An F/A-18 Hornet from USS *Carl Vinson* performs a supersonic fly-by. The condensation shows the low pressure surrounding the fuselage. At the tail the pressure returns rapidly to ambient so the cloud disappears. (US Navy)

An SST has to operate in an extraordinarily hostile environment. At Mach 2 it experiences a freezing airflow but of such force that the fuselage is heated to the boiling point of water and shock waves tear at every angle on its airframe. Only specially equipped military aircraft had ventured to these extremes, and then usually only for minutes at a time. The SST was designed to carry ordinary airline passengers in complete comfort and safety for

hours at a stretch. Could the fusion of British and French philosophies possibly produce such a craft?

Judging from the expected timescale of the project there was confidence that success would come quickly. The physics of obtaining lift throughout the speed range was understood. The loss in aerodynamic efficiency at speeds above Mach 1 would be more than compensated for by the improvement in the efficiency of the intake and engine combination achievable at Mach 2. A certain amount of ingenuity would be called for in some areas – notably in the engine air intake, air conditioning and fuel systems. Novel techniques, like the redistribution of the fuel in flight to maintain the balance of the aircraft, would have to be developed.

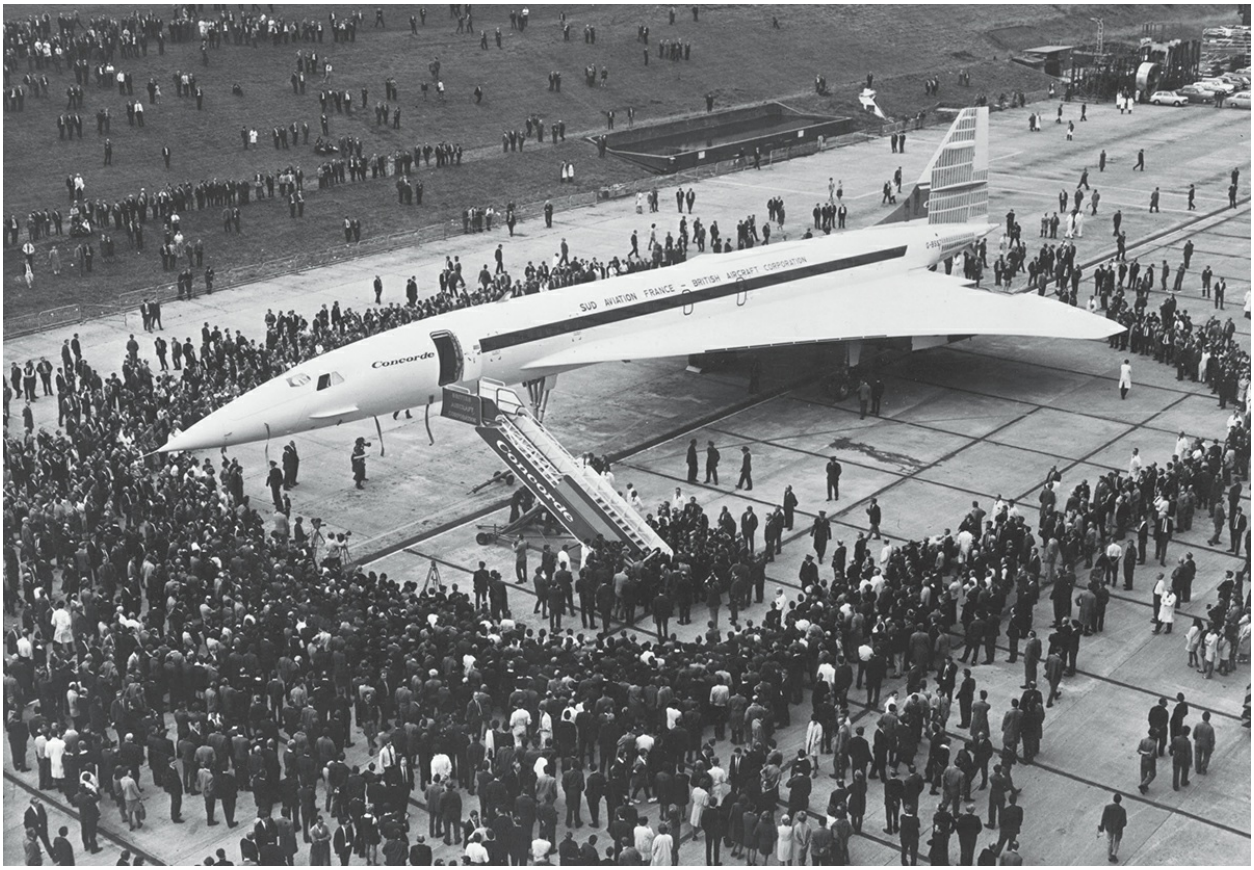
The aircraft would also need to behave in a way that pilots had been trained to expect. A slender delta-winged aircraft with no horizontal tail surfaces is less 'speed stable' so behaves differently from a swept-winged aircraft with a tail. A conventional aircraft is designed to pitch up if the speed increases and vice versa to restore the original airspeed. This effect is achieved with no control inputs, through the tail surface being forced down aerodynamically due to the increasing air flow and vice versa. Also the delta's ratio of pitch to roll is different from a conventional aircraft because of its length and small wingspan. Gordon Corps, Chief Test Pilot of the CAA's Airworthiness Division, responsible for issuing Certificates of Airworthiness, insisted that an automatic speed stability system be built into Concorde. Regarded as an unnecessary refinement by most Concorde pilots, it was fitted nevertheless. However, the electronic auto-stabilisation, in the three axes of pitch, roll and yaw was essential.

TAKING SHAPE

Making the aircraft safe, yet light, would stretch the powers of the designers. Having been built, the structure would have to be tested to limits beyond those that could be explored in flight. To achieve that, two full scale versions of the airframe would have to be dedicated to

ground testing. All the stresses and strains of high-altitude flight would be applied to them, including the repeated heating and cooling of the airframe experienced on each supersonic flight.

Very high altitude flight is advantageous to an SST since it can fly at a far lower indicated airspeed for a given true airspeed. At 60,000ft travelling at Mach 2, or 1,150 knots true airspeed, Concorde only 'feels' 435 knots of airspeed. Fighter aircraft have to be built with sufficient strength to withstand turbulent air at indicated airspeeds in excess of 700 knots. Such a speed, apart from being quite unnecessary for an SST, would call for a stronger and therefore heavier structure. With the very small margin available of payload weight to total weight, the SST could not be allowed to have the luxury of a high indicated airspeed limit. The indicated airspeed limit on Concorde varies with altitude, reaching a maximum of 530 knots at 43,000ft. A typical limit for a subsonic passenger jet is 350 knots.



Britain's Concorde prototype being rolled out of its hangar at Filton, Bristol. (Photo by Fox Photos/Getty Images)

The disadvantage of flying at very high altitudes (compared to a subsonic airliner) is that the fuselage has to be made strong enough to withstand high differential pressures. To give a 'cabin altitude' of 6,000ft when the aircraft is at 60,000ft requires a differential pressure approaching 11lb per square inch (psi). With an 8psi limit, typical for most subsonic airliners, the cabin altitude would be over 7,000ft when flying at 37,000ft.

Large aircraft require a multitude of systems: electrics, hydraulics, navigation, undercarriage and flying controls, to name but a few. Systems fundamental to the safety of the aircraft must have back up systems. Some systems on Concorde were to have additional back up systems. For instance, Concorde was fitted with four methods of lowering the undercarriage: two of them from different hydraulic sources; one by letting it down by its own weight; and a fourth by use of compressed air. Before passengers could be carried, every conceivable combination of failures and consequent recourse to back up systems had to be explored.

Safety at the level of system failures was one thing, but would the SST be able to survive a potentially catastrophic incident? Would it be controllable at Mach 2 following the simultaneous failure of two engines on one side? The answer had to be 'yes'. But when the British and French prepared to join forces in 1961, experience of such incidents had not been good. The world's first big supersonic jet was the four-engined, delta-winged American Convair B-58 Hustler. It was not capable of surviving a single engine failure at Mach 2, let alone two on the same side. Even flight at other speeds was risky – a B-58 crashed during a display at the 1961 Paris Air Show. Deaths of B-58 crew were common occurrences in spite of their being housed in escape capsules. It would be small comfort for a Concorde passenger to think that the pilot and crew were similarly protected while they were not.

No country had yet been called upon to award a C of A (Certificate of Airworthiness) for the transport of the fare-paying public in an SST. New rules had to be introduced. Every detail of the new aircraft would suffer the expert scrutiny of the civil aviation authorities of Britain, France and, as a prospective purchaser, the United States.

A COMPLICATED BEGINNING

There are conflicting requirements on any aircraft. On an SST such conflict is extreme: too strong and it would be too heavy; if too efficient at one speed, it might be unflyable at another; highly efficient engines at Mach 2 might be noisy on take-off. Compromise and ingenuity would find solutions, but the margins were narrow. The payload to maximum take-off weight on the long-range airliners of the 1960s was 10%; the Boeing 747s of the 1970s gave 20%. The SST would be lucky to achieve 5% over a 3,500nm (nautical mile) range. A tiny error in performance would remove the ability to carry any payload between London and New York.

The small predicted payload to weight ratio did not daunt the supporters of the SST. The difference would be restored by the greater number of Atlantic crossings achievable by one aircraft. The price of fuel was expected to remain constant, even fall a little! The sonic boom, however, did cause concern.

An aircraft travelling at speeds above Mach 1.15, depending on atmospheric conditions, causes a double boom to be audible on the ground. Should this preclude supersonic flight over populated land, the medium-range SST espoused by the French would be a non-seller, as there are too few viable medium-range routes which fly over the sea.

In 1966 the designers hoped that two very similar SSTs would be built. The medium-range version would have space for more passengers and less fuel, whilst the long-range version would reverse the mix. It turned out, however, that each design compromised the other. Coupled with thoughts about the sonic boom, this finally killed off the medium-range SST.

Nevertheless, the two prototype Concordes, 001 and 002, the building of which had commenced in April 1965, could not be described as long-range SSTs. The same applied to the two pre-production Concordes – 01 and 02, later renumbered as 101 and 102. The final production version of Concorde (serial numbers from 201 to 216) was not only a long-range SST but also came very close to Archibald Russell's original specification – the Bristol Type 198. Designing, tooling and building three different versions of Concorde

added very greatly to the cost and the time spent on the project. Additionally, mainly for political reasons, the whole project had duplicate headquarters, at Filton and Toulouse. With hindsight it is absolutely remarkable that such a fine aircraft as Concorde could have had such a complicated beginning.

No less troublesome to the project were the various changes of government on the British side. No sooner does one government take over, its predecessor's activities come up for scrutiny. The Labour Government which took over from the Conservatives in 1964 was a case in point. It was only the treaty between France and Britain jointly to build an SST – an agreement that had been registered in The Hague – which prevented cancellation of the project.

Pressure had also been mounting from America for Britain to abandon various aviation projects – among them the TSR2 (Tactical Strike Reconnaissance) supersonic military aircraft. Why should the United States lend money to Britain only to fund aircraft projects which would compete with the American aviation industry?

At industry level the story was different. From Boeing (the company chosen to build the US SST) came support for the European project. At first sight it might seem odd that a rival should support a rival, but this support was mutual. Each company felt that if its rival was allowed to continue, then its own chances were bettered.

Concorde assembly at the BOAC factory at Filton, Bristol, *c.*1975. (Photo by SSPL/Getty Images)

FIRST FLIGHT

On 2 March 1969, the day before I joined BOAC, these difficulties lay in the future. On that day, André Turcat (director of Flight Test Aerospatiale) was to attempt to take Concorde 001 into the air for the first time from Toulouse. Bad weather had delayed the flight, but at last Concorde 001 was lining up for take-off. About 30 seconds' worth of take-off run would prove whether the preceding seven years had been spent in vain; they were not, she flew. It was an amazing moment.

Only the low speed and low altitude range of the flight envelope (combination of speed and altitude at which an aircraft is allowed to fly) were to be explored on this day. Did the indications of speed and altitude correspond to those of the chase aircraft? The undercarriage was not even raised. Take-off and flight proved to be possible, but

could the slender delta be made to land?

Some 35 minutes later Concorde 001 was on final approach at Toulouse, and all looked well. On touchdown, two clouds of dust and smoke were whisked from the wheels into the vortices over each wing. Maskell and Küchemann had been right: a separated airflow had given lift even to an aircraft as big as Concorde. Some minutes later, surrounded by cameras and microphones, André Turcat announced in French and English, 'The big bird flies.' I hoped from that moment that one day I would have the privilege of piloting Concorde. It had been so exciting to see the take-off of the prototype of such an interesting project, that I longed to learn how it was done.

Just over one month later, the British-assembled prototype Concorde 002 took off from Filton with Brian Trubshaw (Chief Test Pilot of BAC) at the controls. John Cochrane was the co-pilot and Brian Watts the flight engineer. As the flight deck is over 35ft above the runway on main wheel touchdown, of key assistance in landing is the radio altimeter. Concorde has two radio altimeters, and on this occasion both failed, so the landing at Fairford, Concorde's British test flight base (on account of its long runway), had to be done by eye. It was a 'firm' landing. As Brian Trubshaw put it later: 'We arrived about half a second early.'

Just under six years of testing and building were to elapse before Concorde's first commercial flight. During that time, crises of all sorts presented themselves: environmental, political, technical and economic. Concorde's surviving of them all ranks as a modern wonder of the world.

Test pilots André Turcat and Brian Trubshaw at BAC headquarters in Bristol, 1968.
(Photo by Dennis Oulds/Central Press/Getty Images)

MAINTENANCE OF CONCORDE

Once in service, Concorde underwent a series of checks at specific intervals, but every 12,000 flying hours, each aircraft was submitted for a 'major' check. In BA, the last aircraft in the fleet to achieve 12,000 hours was G-BOAG (aircraft 214). A 'major' on Concorde lasted about five months, which included a month for the structural work associated with the Crown Area Modification.

The Crown Area Modification strengthened the top of the fuselage. At 'rotate', during take-off, the elevons moved up, placing a down force at the tail. The reaction to this stretched the top of the fuselage as the aircraft was pitched up. Calculations suggested the need for minor reinforcements along this section. In spite of this, a computer model was

made of the structure of G-BOAF. About 40 strain sensors were fitted and the data they gathered over several flights was analysed. A far more accurate picture of the structure was formed than was possible when Concorde entered service. This proved that the designers had erred on the right side. Concorde was exceedingly strong, albeit at the cost of a small weight penalty.

Before the Crown Area Modification could begin, the aircraft had to be 'candlesticked'. This involved being jacked up in such a way that the skin experienced zero stress; adjustments were even made for diurnal temperature variation. Then at two positions over the top circumference of the fuselage a double row of fasteners was removed. Into each resulting hole was forced a mandril. The ensuing stress strengthened the surrounding metal. The mandril was then removed and a new fastener put in place. Since all this took place at room (or hangar) temperature, it was called 'cold working'. Included in the modification was the addition of one strap over the top surface of the fuselage just to the rear of the centre door.

THE LIFE EXTENSION PROGRAMME

With the intention of keeping Concorde flying well into the future, the Life Extension Programme was also introduced. Bitter had been the experience of the builders of the early Comets – at least two of which, in the early 1950s, had suffered explosive decompression. Hence the requirement to build two Concorde fatigue specimens and subject them to forces, vibrations, heating and cooling to an excess of that expected during normal service. Before being shut down in 1985, the test rig at Farnborough achieved 20,000 'supersonic flight cycles'. After 6,700 cycles – a third of the total – it was agreed that more stringent airframe inspection procedures would have to be established. These constituted the Life Extension Programme.

Concorde G-BOAB in flight. (Photo by Etienne de Malglaive/Gamma-Rapho/Getty Images)

Rather than the supersonic flight cycle, the yardstick established for measuring Concorde life subsequently became the reference flight (RF). Every flight was counted but the figure was modified in proportion to the take-off weight. A flight at over 170 tonnes take-off weight counted as one RF and less than 120 tonnes as half an RF. By 14 June 1996 the oldest BA Concorde had achieved 6,042 RFs and the youngest 3,792 RFs. The initial Life Extension allowed for 8,500 RFs. Three years before this total was reached, a review would take place, modifications be made (if necessary) and different inspection procedures (if required) established to take the life up to 10,000 RFs.

To make the various inspections required by the Life Extension Programme simple, modified aircraft were fitted with borescopes. These are visual devices – using fibre optics or even micro TV – capable of seeing round corners to examine the more inaccessible parts of the fuselage without dismantling internal structures such as galleys.

Due to thermal heating during the supersonic cruise, Concorde's fuselage was less prone to corrosion than that of a subsonic aircraft. Fluids evaporate from the inside of an aircraft skin regularly heated to 100°C (212°F); in contrast they condense on the inside at –30°C (–22°F). On Concorde it was areas where fluids could be spilt onto the structure at room temperature, for instance around the galleys, that needed to be subject to greater scrutiny. During checks very minor blemishes were 'blended out' by careful metal polishing; if larger, then the piece was completely renewed.

Concorde 002 stationary on a runway. A crew of mechanics are checking the rear of the plane. (Photo by SSPL/Getty Images)

There was also the question of whether there would always be a sufficient supply of spare parts over the projected lifetime of the aircraft. When necessary, new parts had to be built from scratch. For instance, new rubber sheathing to the weather radar cable guides had to be made out of a non-carcinogenic material and electronic circuit

boards for the air intake computer units were constructed as new items.

TECHNICAL MODIFICATIONS

Just after Concorde went into service, three important modifications were made: thinning of the lower intake lip; approval of a further aft centre of gravity for take-off; and stiffening of the main undercarriage oleo legs. The first modification improved supersonic range, enabling the Bahrain/Singapore sector, at the time routed to the south of Sri Lanka, to be flown direct. The second allowed more fuel to be carried in the rear fuel tank, thus improving take-off performance; this is due to the increased 'flap effect' of the elevons (angled further down to compensate for the more rearward centre of gravity). The third, a modification to the undercarriage, allowed Concorde to use some of the more undulating runways around the world. During the route proving phase (prior to entry into service), violent oscillations had been experienced on take-off at Singapore.

A later modification involved fitting strain sensors to the main undercarriage bogie beams. Should a tyre have deflated below a certain speed during take-off, the twist on the beam would have caused a warning light to illuminate calling for the take-off to be abandoned. This avoided overstressing the neighbouring tyre, risking a burst and debris entering the engines.

Apart from an improvement in the computer software of the Inertial Navigation System and the fitting of the Traffic Alert and Collision Avoidance System (TCAS) no other significant modifications were made.

Concorde in flight, about to come in to land at Heathrow. (Nicolas Asfouri/AFP/Getty Images)

Occasionally, changing legislation means that airliners must be fitted with new avionics. After a specified date, the United States would not accept an airliner, even Concorde, into its airspace without TCAS. First somewhere had to be found on Concorde's densely packed instrument panel for the display; then the detector aerials had to be fitted. A solution was found for the former, but due to becoming overheated during supersonic cruise, the aerials refused to work. The deadline passed… Months of special exemption were in fact allowed before the problem was finally solved.

Could the electromechanical instruments (artificial horizon, compass etc.) on Concorde have been replaced with television screens? These are found on later airliners with computer generated display images of similar but improved instruments. This was possible; but very expensive. The expense lay not so much in the purchase and fitting of

the equipment, but in the necessary certification process – six months of static testing, six months of test flying without passengers followed by one to two years of revenue flying.

In 1996 the average Concorde had flown the same number of hours as a four-year-old Boeing 747, achieved the same number of flights as a two-and-a-half-year-old Boeing 737 and was in the same condition as a three-year-old Boeing 757. That Concorde was kept in such superb condition was due, in particular, to the dedication and expertise of the ground engineers of both BA and Air France.

All might, majesty, dominion and power – or in this case thrust. By any standard it was an awesome sight. (Mark Wagner/aviation-images.com)

SERVICE HISTORY

Concorde G-BOAF above the clouds. (© John M. Dibbs)

On 21 January 1976 I stood with my wife, camera at the ready, at the western end of runway 28L at London's Heathrow airport. We heard the distinctive roar of the four reheated Olympus engines. Concorde G-BOAA came into view, landing gear retracting as she climbed to the west prior to turning to the south-east en route to Bahrain. As the British Concorde reached her subsonic cruising altitude over the English Channel, the crew heard that the Air France Concorde F-BVFA had had an equally

successful departure. Commercial supersonic services had begun.

OPPOSITION TO THE SST

At first, there was vociferous opposition to SSTs in general and Concorde in particular. The criticism came from all quarters: journalists (on both sides of the Atlantic), an English bishop, politicians (mainly from America), and many other individuals. Their arguments were based on economic and environmental grounds and were often completed with the question: 'What's the use of people travelling so fast in any case?'

Of the most serious concern to the critics was the noise that they believed Concorde would cause at airports. For efficiency at supersonic speeds, SSTs had to be fitted with engines which have a high velocity jet efflux. The shearing effect of this efflux with the static air to the rear of an aircraft causes the major part of the noise. Consistent with retaining an efficient engine, Concorde's manufacturers had gone to enormous lengths to reduce engine noise. They had concentrated on two areas. One was to break down the sharp boundary between the moving and static air and the other was to try and increase the quantity of air flowing through the engine so that it would give the same thrust with a lower exhaust velocity.

Retractable spades were fitted in the exhaust duct. They were angled to splay out the exhaust, in order to break up that noisy boundary between the static and moving airflows. Although promising in miniature, they were ineffective at full size. More successful was the use of the secondary nozzles (buckets), which, during slow speed flight (less than 250 knots), entrained static air into the exhaust stream. In supersonic flight they formed a divergent duct. Then, on landing, to assist deceleration they were moved to deflect the exhaust flow 45° forwards to give reverse thrust.

The second line of attack on noise was to increase the mass flow through the engine after take-off. Once airborne there was sufficient airspeed to avoid the risk of starving the engines of air and causing a

surge (backfire), so the laws governing the area of the primary nozzle, responsible for controlling the low pressure shaft, were rescheduled. It now turned faster, increasing the mass flow, so reducing the exhaust velocity, and therefore the noise, without loss of thrust. It was a form of 'variable' cycle engine, which would be very desirable for a Concorde successor.

Whatever the manufacturers achieved in the way of noise reduction, the crews, having reduced to minimum thrust consistent with climbing to comply with noise abatement procedures, had to eke out every last ounce of the aircraft's performance. However, such procedures had not been finally and accurately formulated for use during the route proving flights flown by Concorde during the summer of 1975. Concorde was thus rather noisier than she should have been, with the result that the American anti-Concorde lobby found some rather willing allies in Britain.

US LANDING RIGHTS

Meeting at Dulles tower. Scheduled Concorde services to Washington's Dulles airport began on 24 May 1976. (Photo by Keystone-France/Gamma-Keystone via Getty Images)

The worst aspect of the anti-Concorde campaigners was their indifference, almost pleasure in denying Concorde a fair noise trial at JFK. There was much discussion in the media about this but eventually, when services began, the combination of the relatively light take-off weights (less fuel is required on a New York to London sector than vice versa) and the meticulous application of the noise abatement procedures

kept Concorde's noise well within limits. The protestors melted away. After that Concorde made many firm friends with the people of New York.

For Concorde to succeed she needed landing rights in the United States, and at New York in particular. On 4 February 1976, after protracted wrangling, the US Secretary of Transportation, William T Coleman, finally gave approval for BA and Air France to commence services for a 16-month trial period; one Concorde each per day to Washington and two each per day to New York. On 24 May 1976 Concorde services began to Dulles airport at Washington, owned by the Federal (US Government) authorities.

Landing Concorde at Dulles International Airport, Washington, was one thing, but permission to do so at Kennedy airport, New York, owned by The Port of New York Authority, was another. Coleman had implied that Federal pressure might be brought to bear on the Authority, but it became increasingly apparent that there would have to be a legal battle before Concorde could gain rights into New York.

Still unwelcome at New York, Air France Concorde F-BVFB photographed on a stopover at a US Navy air station, 1977. (PH3 Caffro/US Navy)

Those rights were finally granted, and amidst threats of the greatest car-borne anti-SST demonstration, Concorde 201 (F-WTSB) arrived in New York on 19 October 1977. In command was Aerospatiale's Chief Test Pilot, Jean Franchi, and on the flight deck with him were Captain Brian Walpole (BA Flight Technical Manager) and Captain Pierre Dudal of Air France. The following day with Captain Walpole in command, Concorde took off from runway 31L (the left-most of the two north-westerly facing runways at New York). For the first time, Concorde made the famous left-hand climbing turn, started at 100ft above the runway. That turn, which was regarded as cheating the noise meters by some critics, had been the subject of much practice, both at other airfields and in the Concorde simulators. The turn, the maintenance of the correct speeds, the cutting back of the thrust, the reapplication, the cutting back and finally the re-application of thrust had been calculated precisely to correspond with Concorde's proximity to noise sensitive areas. The take-off was a success, the noise minimal. In one sense the protestors had won a great victory: Concorde had been made to be acceptably quiet and other airliners had better follow Concorde's example. On 22 November 1977 BA and Air France commenced supersonic services to New York.

CONCORDE IN A CLOSE SHAVE

The author on the flight deck. (Author Collection)

In January 1976 the British Airways Concorde went into service to Bahrain. In May a second destination was added, London to Washington DC. BA hoped that schedules to New York would soon follow, which would require more flight deck crew. The 'conversion' (mainly from VC10s and Boeing 707s) course for Concorde pilots consisted of four phases. The first covered the theory, the second flying on the simulator, the third learning how to land the aircraft (the simulator was not considered sufficiently realistic for landing so actual practice was a requirement) and the fourth flying down the route. Once these four hurdles had been jumped, the crew member would no longer have to be monitored by an instructor.

This story concerns the park brake on Concorde. Once the aircraft is brought to a stop, using the toe brakes on the rudder pedals, the brakes are set to park by a lever which is situated on the right hand side to the rear of the central panel. This position makes it awkward for the pilot in the left hand seat to operate. There are three selections, forward for 'normal' braking, middle position for 'standby' braking and rear position for applying the park brake.

On one occasion, Concorde was due to fly from Heathrow to Brize Norton for the trainees to perfect the landing technique. A trainee captain was in the left hand seat, with the training captain in the right acting as his co-pilot and instructor. As a Concorde instructor I was seated in the jump seat directly behind the captain's. We were taxiing out to runway 10 Right (now 09 Right – the southerly of the two east facing runways at Heathrow). On arriving at the holding point, we stopped a safe distance behind a Trident. The trainee captain then attempted to set the brakes to 'park' by pulling the lever rearwards, its furthest aft position. This is an awkward manoeuvre from the left hand seat. The lever became stuck between 'stand-by' and 'park', rendering both the toe brakes and park brakes inoperative. At idle thrust even at maximum take-off weight (185

tonnes) it was difficult to keep the speed down. Frequently we had to wait whilst the brakes cooled down to less than 220° C (red lights off). At less than 115 tonnes we accelerated smartly towards the Trident which now loomed dangerously close, the toe brakes were unresponsive and it was not possible to set the park brake, so a smash seemed inevitable. The pitot tube on the pointed nose of Concorde would be strimmed by the whirling turbine of the Rolls-Royce Spey. I wondered how serious the fire was going to be. Should we use the rear exit slides? Had they been set to 'flight' (so that the inflatable slide would deploy automatically as the door opened), how quickly would the emergency services extinguish the fire and would the damaged Concorde be reparable? I could imagine the headlines, 'Supersonic Airliner out of control at 10 mph', and 'Concorde Nose Impales Trident Engine'. It was still a sensitive time for Concorde and criticism from the press had to be avoided at all costs. I braced myself for the collision and the aftermath. Luckily the training captain spotted the cause of the trouble. He grabbed the brake lever and shoved it into the park position. Concorde lurched to a stop five metres from the Trident engine. All eight brakes registered an 'over torque', but an expensive embarrassment had been averted.

IN SERVICE

Had there been no delay in starting the New York service, there might have been further orders for Concorde. But however 'well dressed' Concorde had appeared, no purchasers were forthcoming while she had 'nowhere to go'.

In December 1977 BA, in conjunction with Singapore Airlines (SIA), extended the London to Bahrain Concorde service to Singapore. During performance and hot weather trials in September 1974, the first 'production' Concorde (G-BBDG), with Brian Trubshaw and Peter Baker (Assistant Chief Test Pilot BAC) at the controls, had flown supersonically over India. Supersonic overflying permission was now withdrawn so the Concorde route to Singapore had to go to the south of Sri Lanka, adding some 200nm, or ten minutes flying time. By December 1977, minor modifications and improved operating procedures had increased Concorde's range, so what would have been unattainable in early 1976, was by then quite possible. However, after three return flights the Malaysian Government withdrew flying rights over the Straits of Malacca. After more negotiations with the Malaysians the route reopened in January 1979 and was operated until

November 1980. Concorde was flown to Singapore by BA crews with the cabin alternatively being staffed by BA and SIA cabin crews.

In 1980, world recession brought about a drop in Concorde's load figures between London and Singapore. This, coupled with the financial arrangements between BA and Singapore Airlines, put a greater share of the burden of loss onto BA, finally causing the route to be abandoned. A particular Concorde had been earmarked for use on this route (G-BOAD), being painted in Singapore livery on the left-hand side, and in BA colours on the right. This was the first and, by 1990, the only Concorde to have appeared in colours of an airline other than those of Air France or BA. Sadly, as the route closed down, the BA flight deck crews returned home from their postings in Singapore. With an excess of crews, some would leave and others be redeployed in the airline. Morale, which was usually very high, took a temporary dip. G-BOAD was restored to BA livery.

Earlier that same year the agreement between Air France, BA and Braniff which enabled Concorde to continue through to Dallas, Texas, from Washington (changing to an all American crew just for this sector), was wound up. The route had lasted from January 1979 until June 1980. Braniff was, by 1996, the only American airline to have operated Concorde, albeit subsonically. They had hoped to gain experience with the aircraft for eventual supersonic services to South American destinations. In the meantime Concorde's high profile would have helped their marketing effort. But world recession and the deregulation of American internal airline routes had stretched Braniff's resources, so their Concorde operation experienced unacceptably low loads.

CONCORDE CHARTERS

To give Concorde a boost when services were declining, several Concorde crew members chartered the aircraft, giving people flights on Concorde at a fraction of the cost. One of the first to do so was Concorde pilot Brian Calvert. He took the regulars of his local pub, 'The Bell', for a short supersonic flight. In 1981 my wife and I chartered Concorde to celebrate Britain winning the Schneider Trophy contest. The last contest was won in 1931 by an RAF team captained by

Squadron Leader AH Orlebar (a cousin of mine). In 1981 Concorde flew on two occasions at 340mph around the final course which was situated between the Isle of Wight and Portsmouth (England). The speed of 340mph was chosen since it had been the average speed of Flt Lt John Boothman's winning Supermarine S6B in 1931. Two Schneider trophy pilots flew on Concorde to celebrate the 50th anniversary of the final victory: Air Commodore D'Arcy Greig (1929 team) and Group Captain Leonard Snaith (1931 team).

FINANCIAL REVIEW

On Concorde's financial side, a review in February 1979 of the ability of BA to make a profit with Concorde had concluded that it could not do so by ordinary commercial standards. Accordingly the Labour Government decided to write off the £160 million of Public Dividend Capital (PDC) associated with BA's acquisition of its five Concordes. In November 1979 an Industry and Trade Select Committee, chaired by Sir Donald Kaberry MP, was convened to investigate Concorde. Quoting from the report of their investigations (published in 1981): '[the writing off of £160 million PDC] meant that the whole fleet, including the initial inventory of spares, was entered in the BA balance sheet as a fully depreciated asset – that is to say a gift from the taxpayer. For their part BA had to pay to the Government 80% of future Concorde operating surpluses (the so called 80:20 agreement), though these were to be calculated after the offset of any operating deficits incurred after the review and also the amortised cost of any post-review expenditure.'

During the commercial life of an aircraft, its manufacturers not only undertake to supply spare parts, but just as importantly to supply a 'support' service in the form of carrying out development work and monitoring performance, suggesting, or insisting, where necessary, on improvements or modifications. Such support is usually financed out of the profits from the sales of spare parts and ancillaries to airlines operators.

In the case of Concorde, monitoring of the aircraft's performance was, in the early days of operation, a very expensive business. Not least of those expenses were the two test specimens – full-sized Concorde fuselages dedicated to being tested on the ground. Quite early in the

programme the stress test specimen in France had been purposely tested to destruction, but by 1980 the one at Farnborough was still costing several millions per year to run. Profits through sales of spare parts would not raise anything like enough to pay for the Farnborough rig, nor enough to pay for the necessary, but diminishing, development work associated with Concorde. Accordingly, the four manufacturers – Aerospatiale, British Aerospace (successors to BAC), Rolls-Royce and SNECMA – were funded for their responsibilities to Concorde by their respective governments.

G-BOAD was the only BA Concorde to have been painted in a livery other than British Airways or Air France – carrying Singapore Airlines' livery on the left side only. (Chris McKee)

In October 1978 the jigs used to manufacture Concorde were removed from the Brabazon Hangars at Filton for storage at Wroughton, near Swindon in Wiltshire, against the possibility that there might be a demand for more Concordes. However, the French had, by

December 1977, not only removed but disposed of their jigs; with their capability gone further production of Concordes would have been an extra expense. On 31 December 1980 it was announced that the production phase of Concorde had ended, but it was not until October 1981 that disposal to scrap merchants of the stored British jigs began.

The Select Committee had to face some rather unpalatable truths. No more Concordes would be sold, the funding of the manufacturers would bring no return to the governments, and the two airlines concerned did not seem able to operate Concorde profitably. It had been asked to make recommendations specifically on the question of costs due to be met out of the public purse. Was there, it tried to answer, a case for continued expenditure, which although unjustifiable in financial terms, might confer other benefits on the UK, such as prestige or the basis for starting a second generation SST? Then, more sinisterly, from Concorde's point of view, the Committee was to investigate how the cost of immediate cancellation would compare with the cost of continuing and how a proposal to cancel would affect relations between the UK and France.

It appeared that the writing was on the wall for Concorde, the more so since the return of a Conservative Government in May 1979. There is no doubt that they wished Concorde to continue if at all possible, but not at any price.

The change of government in Britain also saw a change of policy towards the nationalised industries. In Febuary 1981, Ross Stainton retired as Chairman of the BA Board, and Sir John King took over. He had been charged by the Government to prepare the company for privatisation. Having suffered disappointing financial results, attributable to the world recession, the moment had arrived to study every aspect of the airline with the view to cutting costs and increasing revenue.

Following the period of recession, the restoration of morale in BA was regarded as a most important part in its march back to profitability. To this end, 'profit centres' were set up within the airline. One such centre was the Concorde Division. In May 1982, Captain Brian Walpole, who had been Flight Manager Technical, was asked by Gerry Draper (BA Commercial Director) to become General Manager

of this new division. As his assistant he brought with him another Concorde pilot, Senior First Officer WD (Jock) Lowe. Broadly they divided their responsibilities into two, Walpole looking into ways of increasing revenue and Lowe at ways of reducing costs. Within months of these new appointments, Concorde was faced by a new crisis. In August 1982 Ian Sproat MP wrote to Sir John King stating the Government's intention to cease funding the British manufacturers' support costs for Concorde and asking BA if it wished to take on this responsibility. If BA were to decline, in the words of Keith Wilkins (Head of Planning, BA): 'The supersonic project would terminate.' Termination in Britain at this stage would probably have meant termination in France as well. The date set for this was 31 March 1983.

The BA reply indicated that they were very willing to examine the possibility of taking over the support costs, but they would have to be given time to examine the implications. The Government agreed to another year being made available before the axe would finally fall on public money funding the British manufacturers.

Slowly and inexorably the negotiations eroded the major outstanding differences between the Government and BA. In the end a sum had to be agreed which BA would pay to the Government for all the Concorde spares, Concorde G-BBDG (202) which was grounded at Filton minus engines and much equipment, and the Farnborough Concorde test structure, as well as buying its way out of the 80:20 agreement. In March 1984, 18 months of detailed analysis were brought to a swift conclusion. In a meeting lasting not more than a quarter of an hour, Gordon Dunlop (Finance Director of BA) and the Government representatives agreed on a figure: £16.5 million. Concorde was saved.

A Conservative Government spawned Concorde and ensured its right to life through an unbreakable treaty with France in 1962. Twenty-one years (and a few months) later, another Conservative Government severed almost all its financial connections with Concorde: the supersonic airliner had come of age. With expanding charter services and improving figures on the scheduled routes (London to New York and London to Washington and Miami), the commercial future of Concorde in BA looked bright.

ROUTES AND PASSENGERS

Concorde's principal scheduled services were from London, Paris or New York. Over the winter months there was, for BA, a once, sometimes twice, weekly scheduled service to Barbados. In 1980 BA, in association with Singapore Airlines, discontinued the London/Bahrain/Singapore route. In 1982 Air France ceased Concorde flights to Rio de Janeiro, Caracas, Mexico City and Washington. In October 1994, after 18 years, BA dropped their London to Washington service, the Miami extension to that route having been discontinued by January 1991. By the cutting of the latter two routes, BA saved 600 supersonic sectors per year, thus prolonging Concorde's useful years of service.

Despite a difficult start, Concorde eventually became a welcome visitor to many US destinations. Here Concorde is shown landing at Seattle's King County Airport in 1984. (Bettmann/Getty Images)

On 2 April 1996, Pepsi-Cola launched their 'livery'. F-BTSD in the new Pepsi colours visited ten cities, including here Dublin, and was restored to Air France colours after two weeks. (Jonathan McDonnell)

With the cessation of the direct thrice weekly Concorde service to Washington Dulles, a daily morning connecting flight was established between New York and Washington National. This took about 90 minutes longer than the old direct flight. In compensation, 'National' was 45 minutes closer by road to the US capital than 'Dulles'.

In good economic years Concorde was extremely profitable. It even survived the recessions of the mid-1980s and early 1990s. In 1996 BA's twice daily service between London and New York, at normal Concorde fare levels, was achieving load factors westbound of 70–80% and eastbound 50–60%. For Air France the single daily service between Paris and New York achieved an overall load factor of over 60%. By October 1987 the BA Concorde had carried its 1 millionth scheduled transatlantic passenger; the figure for Air France being 677,000. By the

20th anniversary of Concorde operations (21 January 1996), Air France had carried a total, including charter passengers, of over 1.1 million; for BA this total approached 2 million.

Concorde carried more passengers west than eastbound. The supersonic traveller from Europe arrived in New York one hour, from the UK, or two hours, from France, before he had left. Westbound the time change was subtracted from the flight time; eastbound it was added. It would in theory be possible to start a round the world supersonic westbound service with a single aircraft that always left at the same local time.

The reason for the disparity is as follows. Having arrived in New York on the morning supersonic flight, many business people completed a full day's work. Then despite the jet lag, they returned on the overnight subsonic flight, to be ready (or so they thought) for work the next European morning.

A less tiring option, although involving an overnight stay, was to return on the following morning or afternoon supersonic New York to Europe flight. Leaving at 8.45am (local time), on flight BA002, the executive returned to London at 5.25pm (BA004: 1.45pm–10.25pm; Air France New York–Paris on AF001: 8.00am–5.45pm).

For the passenger who originated his trip in the United States, the supersonic day flight was very attractive. This delivered him fresh in Europe allowing easy adjustment to the new time zone.

Concorde was constrained by 'night jet bans'. At Heathrow no aircraft 'movements' were allowed between 11.30pm and 7.00am, at New York, between 10.00pm and 7.00am. Theoretically it was possible to avoid the ban at each end; nevertheless an overnight supersonic eastbound flight was impracticable. A 9.45pm take-off from New York (leaving very little margin for error) could often arrive at Heathrow before 7.00am. Reducing speed to arrive at, say, 7.30am would have defeated the object of Concorde; furthermore, there could still have been complaints about early morning jet noise. In any case, having suffered a very short night's sleep and paid more for the privilege, the passenger could be less comfortable than his subsonic counterpart. For a Concorde successor flying eastbound, there was a potential conflict of night jet bans with the short flight times. This conflict lessened as the

local hour change between points increased. An eight-hour time change between two places with a five-hour flight would make for an eastbound journey equivalent to 13 hours. So a flight departing at 8.00pm would arrive at 9.00am the following day, both times being well within jet ban tolerances.

In BA, charter flights generated 10% of the total revenue from Concorde. In 1996 seven companies regularly chartered Concorde: Cunard, Goodwood Travel, Concorde Spirit Tours, Superlative, Intrav, David Gladwin Concorde Ltd and Yorkshire Charters. Concorde Spirit Tours, founded by American Attorney at Law Donald Pevsner, broke the circumnavigation of the globe record: on 12–13 October 1999 Air France Concorde F-BTSD completed the trip around the world in 32 hours 49 minutes and three seconds.

TRAGEDY AT GONESSE

On 25 July 2000 at 14:43 GMT, the tyre of the number 2 wheel of Concorde F-BTSC burst during take-off. This set in motion a train of events that resulted in the destruction of Concorde 203. Two minutes after starting the take-off roll, the aircraft crashed onto a hotel at Gonesse, 8km to the west of Charles de Gaulle airport, with the tragic loss of all 109 people on board, four on the ground and injury to six others.

News of the accident reverberated around the world. Journalists gave instant analyses, while Jim Naughtie of BBC Radio 4's 'Today' programme was sent to Paris. At Farnborough the flags were lowered to half-mast.

BA cancelled that evening's service to New York and, after some agonising, resumed Concorde services the next day, whereas Air France did not.

In the days that followed, details were revealed about those on board. Of the 100 passengers on Special Flight AF4590, one was an American, one an Austrian, two were Danish and 96 were German. All were en route to New York where they were to join their cruise ship, the MS *Deutschland*.

On Thursday 27 July, a memorial service was held at L'Église

Madeleine in Paris, the same church where, three years earlier, people had paid their last respects to Diana, Princess of Wales.

THE INVESTIGATION

The subsequent investigation was to produce four reports and take 18 months to complete. On 27 July the Bureau Enquêtes Accidents (BEA) issued the first of 14 bulletins or *Comuniqués de presse*. Paraphrased and translated from French it stated:

> Shortly after V_1 ['decision' speed], the 'Tower' (Control Tower) reported seeing flames coming from the rear of the aircraft. Engine number 2 appears to have lost thrust (noted by the crew) followed later by number 1. The undercarriage would not retract. Speed and altitude remained constant and the flight lasted for about a minute. After banking sharply to the left, the aircraft crashed. The remains of tyres were found on the runway, debris was found along the flight path and in a small area at the crash site.

A Preliminary Report would follow at the end of August. The bulletin made two further points. The first mentioned that British, German and American investigators would be included under the auspices of the BEA. The British equivalent to the BEA is the Air Accident Investigation Branch (AAIB).

The second point acknowledged the role of the French judiciary, whose task was to take action should the law have been broken. In France any evidence is 'owned' by the judiciary which can take advice from the investigators. In the UK the evidence is 'owned' by the investigators who work in parallel with the Coroner or Board of Inquiry. The investigator's remit is not to apportion praise or blame. By preventing early analysis of some parts of the wreck, the AAIB felt that the French judiciary had impeded the investigation. This represented a contravention of ICAO (International Civil Aviation Organisation) Annex 13 to which France is a signatory.

On 28 July the second bulletin appeared. Paraphrased it stated that:

> … debris found on runway 26R came from the Concorde's left-hand side including remains of two* (of the four) tyres from the left gear leg. No engine debris was found and evidence suggested that the fire was external to the engines.

On 30 July the third BEA bulletin released more details, including that of the discovery of a portion of fuel tank on the runway. The judicial authority retained this piece. The polythene bag in which they had sealed it became opaque from being handled. Actions like this, said the AAIB, had delayed the investigation.

A tyre burst causing a fuel leak, which was somehow ignited, now appeared as the most likely explanation for the accident.

From the fifth bulletin on 4 August came the announcement that a metal strip about 40cm long, not belonging to the Concorde, had been found among the debris on the runway.

Was this the cause of the tragedy? How did such an object come to be on the runway in the first place?

The answer to the first question appeared to be 'more than likely'. The second question was not answered immediately, but started a debate about runway inspections. The requirement was three times daily. Then it transpired that, due to a fire practice on 26R (runway used by F-BTSC) and 26L, the second inspection had been delayed.

On 16 August the eighth bulletin announced that Concorde's Certificate of Airworthiness had been suspended on the grounds that such an event might easily happen again.

THE PRELIMINARY REPORT

On 31 August the preliminary report was published. Its summary said:

> During take-off from runway 26 Right at Roissy Charles de Gaulle Airport, shortly before rotation, the front right tyre of the left landing gear was damaged and pieces of the tyre were thrown against the aircraft structure. A major fire broke out under the left wing. Problems appeared shortly afterwards on engine number 2 and for a brief period on engine number 1. The aircraft was neither able to climb nor accelerate. The crew found that the landing gear would not retract. The aircraft maintained a speed of 200 knots and a radio altitude of 200 feet for about one minute. Engine number 1 then stopped. The aircraft crashed on to a hotel at La Patte d'Oie in Gonesse.

The preliminary report revealed that extra baggage had been loaded but not properly accounted for; the 'ground' copy of the loadsheet could not be found. Only 800kg of the two tonnes of fuel loaded for the taxi

had been used. The extra baggage and fuel made the aircraft at least one tonne over structural weight for take-off, although this resulted in a negligible difference to performance.

The centre of gravity on engine start was 54.2%, which after taxiing had moved forward to 54%. The report told how data from the recorders had been retrieved. Ten seconds before the start of the take-off run, the cockpit voice recorder (CVR) reveals that the tower informed the crew of a tail wind (easterly at 8 knots) and cleared AF4590 for take-off. If this were a steady wind, then due to the tyre speed limit, the aircraft's performance weight was too great by about 5 tonnes. The crew did not audibly discuss this. In reality the average wind was very light from the north-east. The report said:

> At 14 h 44, the average wind at the threshold of runway 26 was 020°/3 kt and 300°/3kt at the threshold of runway 08 [the reciprocal runway].
>
> All goes normally to V_1 – 33 seconds after start of take-off. Six seconds later, at 175 knots, there is a noise and a second later a change in background noise – the ignition of the fire and engine surge (akin to a backfire). One second later, at 185 knots, the rotation is commenced.

The report shows pictures of the 43cm x 3cm strip of metal that cut the tyre from shoulder to shoulder, and the piece of damaged tyre itself, measuring 100cm x 30cm and weighing more than 4kg. The profile of the cut corresponds to that of the metal strip. On visual inspection the metal appeared to be a light alloy. There is no mention of where it could have come from. The photograph of the 30cm x 30cm portion of fuel tank found on the runway shows that it suffered no impact damage but it was slightly bowed outwards. The mechanics of its ejection from the lower wing surface are not discussed.

Concorde pictured during an Air France commercial flight from Paris to Rio de Janeiro via Dakar. (Photo by Keystone-France/Gamma-Keystone via Getty Images)

There is a runway diagram showing where the debris was found, the tyre marks of the left-hand undercarriage and trail of soot from the fire. Both the strip and the tyre debris were found together on the north side of the runway. This puzzled Alan Simmons, an investigator from the AAIB. Had someone put them together?

Why the rotation was commenced some 15 knots below the calculated V_R ('rotate' speed) has not been satisfactorily explained, even in the final report which was published in January 2002.

Immediately after rotation, there is evidence of an explosion when a piece of concrete (10 x 25cm and about 1cm thick) was detached from the runway, probably where the two left engines surged simultaneously. The increasing angle of attack changed the airflow pattern under the wing. This caused the hot gases to be ingested into the engine via the auxiliary intake, behind the main intake in the floor of the ducting to

the engine. The double surge gave the aircraft an impetus to the left, causing the left gear to strike a runway edge light before becoming airborne.

In conjunction with the physical evidence, the 'traces' of the flight are read and are shown in the report. Each 'trace' plots, with respect to time, a parameter: airspeed, pitch angle, engine thrust and other data. When the 'Black Box' or Flight Data Recorder (FDR) reads 97602.5 seconds, which equates with 41 seconds from the start of take-off, there is a sudden decrease in acceleration. Fractionally later there is a strong lateral acceleration to the left (the double engine surge), which is countered with the application of right rudder. On rotation, the runway's centre line becomes progressively obscured. Without visual cue the Captain maintains runway heading on his compass while the aircraft continues its drift to the left from the impetus caused by the surges. The final report says the lateral acceleration sensed on the flight deck is less than that at the centre of gravity, which helps to explain the lack of track correction.

Within three seconds of the fire igniting and within one second of rotation, the control tower tells the crew there are flames behind them.

Two seconds later (45.5 seconds), at 195 knots, nose wheel off the ground and with less than 2,000m of runway remaining, from the CVR the Flight Engineer possibly says 'stop' [the take-off]. Perhaps he thought there had been a double engine failure, because when he announces 'engine failure' there is a hesitation about which engine has failed. Then he announces 'shut down number 2 engine'. (The standard procedure would be for the Captain to ask the Engineer to shut down an engine once at a safe height. On this occasion, the situation probably appeared to require instant action.)

One second later, the Captain asks for the Engine Fire Procedure. The fire warning for the number 2 engine sounds, supporting their diagnosis. In fact the heat of the fire outside the engine nacelle has set it off. Meanwhile, the number 1 engine recovers to give almost full thrust. The aircraft struggles up to 200ft above the ground. The speed barely reaches 210 knots, 5 knots above V_{ZRC} with three engines operating and gear down. If the number 2 engine had been operating they might

have been able to accelerate despite fire damage but with no way of putting out the fire. V_{ZRC} is the zero rate of climb speed. It varies with the weight of the aircraft, the thrust available and the drag (undercarriage up or down). Below V_{ZRC} climb is impossible.

In the northern hemisphere the wind veers and increases with height. On this take-off, although the wind direction was momentarily due east, the surface wind was generally north-easterly and very light. So on climbing to the west, their airspeed was not augmented with an increasing headwind, if anything, the reverse.

The selections made on the flight deck can be interpreted through analysis of the sound signature of the recorded 'clicks'. For instance, the pulling of the fire handle can be heard 58 seconds after start of take-off. This occurs just after an unknown source, presumably another aircraft, has told them the flames are large and do not seem to be coming from the engine.

When the wheels are down, the gear doors are closed. After take-off, the gear doors are

opened before retraction. Failure of the left door to open may have prevented the undercarriage retracting. (Mark Wagner/aviation-images.com)

The landing gear does not retract. This and the low airspeed (*le badin*) are of great concern to the crew. '*Le badin*, *le badin*,' calls the First Officer. A toilet smoke alarm sounds: smoke in the cabin? Air Traffic Control: offers them 'an immediate return to the field'. This would involve a right turn for a landing to the east on the northernmost of the three runways at Charles de Gaulle (runway 09). The First Officer acknowledges. From 88 seconds after take-off the engine fire alarm sounds continuously and the terrain warning system urges them to 'pull up, pull up'. Then 100 seconds after the start of take-off, the number 1 engine, which had staged a recovery, surges and fails. The crew elects to try for Le Bourget, which by then is less than 2km ahead and slightly left.

At 205 knots with the gear down their speed is 100 knots below the V_{ZRC} for their weight. The aircraft can only decelerate. The rudder loses effectiveness, the aircraft banks to more than 90 degrees to the left and pitches up – the loss of fuel has moved the centre of gravity aft. It turns almost through 180 degrees. In an attempt to level the wings the crew probably throttled back the two right engines. With very little forward speed the aircraft impacts, breaks up and burns. The accident is not survivable.

A Japanese passenger took two photographs of the fire from a Boeing 747 waiting for F-BTSC to take off before crossing runway 26R. By coincidence Jacques Chirac, President of France was on board. Could the 747 have triggered the early rotation? It was too far away to be a factor, on the last of a group of three taxiways.

Once on fire, what else could the crew have done? The final report says that if the crew had tried to stop at the first indication of a problem at 183 knots or when the engineer may have said 'stop' at 196 knots, they would have overrun the runway at 75 knots or 115 knots respectively. Maximum braking on seven wheels and reverse thrust on three engines was used in the calculations. Neither course would have improved their chances of survival. The crew could have done nothing more than they did; circumstances, through a set of cruel coincidences,

had blocked all avenues of escape.

The preliminary report confirmed the decision to keep Concorde grounded, with this final paragraph:

> The Certificates of Airworthiness of Concorde be suspended until appropriate measures have been taken to ensure a satisfactory level of safety as far as the tyre destruction based risk is concerned.

POSSIBLE CONCLUSIONS

On 4 September 2000, the 10th bulletin announced that the metal strip that had caused the tyre burst had fallen from the thrust reverser mechanism of a Continental Airlines DC10. This flight had left for Newark in the United States some minutes before the ill-fated Concorde. The author of the bulletin was at pains to emphasise that Continental had co-operated fully with the investigators.

Several major questions remained unanswered. How was the fuel leak caused? What was the source of the ignition? Why did the landing gear not retract? Did the missing 'spacer' in the left main gear cause Concorde to track to the left?

In each main undercarriage on Concorde there were two 'shear rings' whose purpose was to keep the wheels running straight. The rings were kept in position by a 'spacer'. If the spacer was missing and the undercarriage was retracted, the lower (outboard) shear ring was kept in place by gravity. However the upper (inboard) shear ring, unsupported by the spacer, would fall a little each time the gear was retracted. Once the ring was displaced, the bogie beam could become misaligned by up to 2 degrees in either direction. The bogie beam of the left undercarriage assembly carried wheels 1, 2, 5 and 6. During the accident investigation a BA engineer noticed that the spacer had been missing from the crashed Concorde. How significant was this?

Captain John Hutchinson, along with other former Concorde flight crew, suspected that the lack of the undercarriage 'spacer' was another factor in causing the aircraft to track towards the left side of the runway. For most of the take-off run there were no discernible rubber deposits from the left gear and none from the right gear. There is, however, a photograph in the Final Report showing rubber marks from

the three remaining wheels of the left undercarriage leading up to the broken runway lamp. The track of the two left tyres (numbers 1 and 5) on the left gear is clearly visible in the photograph. To their right, in the direction of take-off, the marks from the flaying remains of number 2 tyre are visible ahead and to the right of the rear right-hand tyre (number 6) track. This suggests that the left bogie was twisted to the right, therefore applying a force to the right. Being behind the centre of gravity, this force would attempt to push the tail to the right and the nose to the left. The left gear would drag more than the right; this too would increase the turning force to the left.

It seems the rubber deposits begin well after the start of the deviation to the left. The point where the rubber deposits appear could have been where the shear ring, normally kept in place by the spacer, was finally dislodged by the shaking of the flaying tyre. What caused the leftward drift?

Number 2 engine was shut down and the number 1 surged, ran down and took over ten seconds to restore itself to full thrust. In this time 1,000m were covered. With such a long period of asymmetric thrust, an application and holding of 20 degrees of right rudder would have been necessary. Initially 20 degrees of right rudder is recorded. For some reason the rudder angle was reduced to, and held at, about 10 degrees. In the case of an engine failure when airborne it was recommended that sufficient rudder be applied to achieve zero (aerodynamic) side-slip. In this condition the aircraft would turn with wings level in the direction of the failed engine. To prevent this turn, about 2 degrees opposite bank is needed. If sufficient rudder only to achieve zero side-slip had been applied and the wings were level, as they would be with the main gear on the ground, a crab to the left would have resulted. The lack of the spacer may not have caused the initial deviation; but may have added to it just before lift off. By how much, if at all, is open to question.

According to Alan Simmons of the UK's Air Accident Investigation Branch, the tracks in the soot suggested that the left wheels had rolled over already deposited soot. Yet the wheels preceded the smoke. Had the wheels been soaked with fuel, which laid a damp trail on which the soot deposited differently? There was a fuel stain on the runway followed by a dry area, then the deposits of soot. According to Ted

Talbot (former Chief Engineer In Service Aircraft BAE) the piece of tank 5 hinged out, before breaking off. The hinge was inboard on the longitudinal axis. Fuel was first sprayed to the left – onto the runway, then downwards to the gear – not onto the runway, finally igniting – leaving soot on the runway. That would explain the observed evidence.

Another conjecture concerns the question of the 'early rotate'. There was neither a call of 'rotate', nor of 'contingency'. Contingency (extra) power is automatically applied if one of the engines fails to give sufficient thrust. The flight engineer, if he spotted an engine problem once V_1 was passed, would manually select contingency thrust and announce that he had done so. It is possible that the captain, on hearing the words 'engine failure', reacted by rotating the aircraft. On rotation he simultaneously applied right rudder to keep straight and then, with the runway obscured by the nose, reduced the rudder deflection to fly with zero side slip. This might explain why the rudder was relaxed from 19 degrees and held at 10 degrees. The crew found themselves in an entirely untrained-for set of circumstances, they heard calls referring to 'long flames behind you' amidst a cacophony of warning sounds which rendered each other uninterpretable.

In such a scenario it is possible that a previously learnt 'conditioned reflex' took over. Captain Marty had started his career flying twin jets. On a powerful twin jet, V_1 (decision speed) is well in excess of V_R (rotate speed). It would be impossible to stop once airborne, so V_1 is limited by V_R. Every six months on the simulator, pilots practice having an engine failure on take-off. The most difficult moment for this to occur is just as soon as the runway ahead disappears from view. So routinely every six months the candidate on a twin jet practises rotating and keeping straight following an engine failure. On four-engined jets there is usually a gap between V_1 and V_R, typically of about 30 knots on Concorde. If a conditioned reflex had taken over, it might explain why when rudder was applied, the rotation was irresistibly initiated – 15 knots too soon.

In no way are these remarks intended to apportion blame; they are written to suggest why certain events occurred, and what can be done to prevent a similar accident. As already mentioned earlier in this book,

the crew of 'SC' was faced by a cruel set of circumstances. Even with unlimited time it is difficult to suggest a better way of handling the incident; the crew of 'SC' only had seconds.

Initial speculation suggested an engine had caught fire. But seen here, the root of the fire is from around the landing gear bay. (Photo by Buzzpictures/Getty Images)

CONCORDE'S FUTURE

The pessimists declared that Concorde was a victim of its slender delta design. To meet all the aerodynamic criteria, the wheels, they said, had been placed too close to the engine intakes. Even if the tyres were stronger, they would only shed heavier pieces of rubber on bursting. To the optimist, historical precedence gave more hope. The will had been there to remedy the fault in Comet 1 for it to return as the Comet 4. A similar spirit had been shown in the case of the Space Shuttle returning to service following the Challenger disaster.

Meanwhile, BA was counting the cost of keeping its flagship inactive; a year's grounding would be sustainable, two probably not. The airline had always maintained that Concorde was profitable, and an indication of this came with the board's decision to take advantage of Concorde's downtime to start a £14 million cabin refurbishment. But without a Certificate of Airworthiness, Concorde was going nowhere, even if Sir Terence Conran was about to refurbish the cabin.

In early November 2000 a meeting was arranged at Gatwick to discuss the options for Concorde's future. The result was a plan of action which sought to:

- reduce fire risk by looking for leak and ignition sources
- study the behaviour of engines 1 and 2 and how hot gases cause engine surges
- validate performance
- check the hydraulics and the reason for non-retraction of the undercarriage.

In a lecture to the Royal Aeronautical Society (RAeS) at Farnborough in February 2002, John Britton spoke about the chain of events that led to the accident at Gonesse.

Starting with an incident that causes a tyre to break up, subsequent events can be traced through the chain depending on their seriousness. Thus tyre debris might cause 'structural expulsion' which would lead to either a major or minor fuel leak. If it is a major fuel leak and there is an ignition source, then this will lead to a 'catastrophe' after take-off. If there was either a minor fuel leak or no ignition source, then there would be no catastrophe. (Ideally, of course, there should be no tyre debris in the first place.)

According to the statisticians, the probability of a tyre burst causing a catastrophe was less than once in 10 million flying hours. In 25 years the Concorde fleets accrued a total of 235,000 flying hours; at this rate a hull loss, resulting from a tyre burst, would occur once in over 1,000 years. The likelihood of a repeat of the Gonesse circumstances was minuscule. Was this the one event in 1,000 years that had merely happened early? That was a risk that the authorities would not take.

There had already been too many incidents with tyres. Until the problem had been solved, Concorde would be grounded. BA and Air France set August 2001 as a target date.

The final report was released in January 2002. It describes some of the research that led to the remedy.

When the tank burst, the fuel was forced vertically downwards, initially at 100 litres per second before it stabilised at an average of 60 litres per second. A fuel stain on the runway before the soot deposits is evidence of this.

Showing no sign of having been impacted, the portion of tank 5 found on the runway must have been forced out of the tank. If so, it showed an entirely new phenomenon. Had the 4.5kg tyre segment caused a hydrodynamic shock to over-pressurise the tank? Possibly, but the fuel tanks of military aircraft penetrated by high-speed shrapnel had burst in a similar way.

RESEARCH AND TESTING

Intense investigation followed. A computer model was assembled to simulate the mechanics of the incident. AU2GN, Concorde's aluminium alloy, is no longer produced, but when some had been tracked down, a full-scale model of tank 5 was built. Centre d'Essais Aéronautique (CEAT) in Toulouse built a gun which could fire 4.5kg lumps of tyre against the mock-up at 106m per second.

On 25 July 2000, a perfectly acceptable procedure had been followed to 'overfill' tank 5 to increase fuel quantity. As the aircraft accelerated, the fuel in tank 5 was forced to the rear, displacing any air towards the front. This effectively meant the tank was full in the vicinity of the external impact point, making it more susceptible to hydrodynamic shock. On the test rig, the impact caused the tank to be deformed inwards (direct mode), then outwards in an adjacent area in compensation (indirect mode). The rig did not burst, but proved the principle.

The computer model, after being hit, shows a wave propagating along the lower tank surface. The skin then ruptures. Whatever the cause of the massive leak, a self-sealing device was required.

Kevlar is the name Dupont gave to the aramid rubber mix it had already developed. It is a light, black, flexible and very tough material suitable for bulletproof vests. Any tank that might be exposed to impact from an exploding tyre would be lined with Kevlar moulded to the interior contours. The Kevlar liner is suspended less than a centimetre above the tank floor, and each cell of the liner has a 4mm hole in it. As the outer skin of the aircraft is warmed during cruise at Mach 2, these holes allow convection of the warmed fuel away from the tank floor.

As the liners were being fitted, it was discovered that the tanks on each Concorde were slightly different in size. The liners had to be made to fit each individual aircraft – 'bespoke tailoring' as one engineer quipped. It was realised that there would be a weight penalty attached to the liners as well as to some 'unusable fuel'. This is the fuel that remains beyond the reach of the pumps, ie below the liner. The average rate of leak at Gonesse was 60 litres per second. The Kevlar liner would reduce such a leak to about half a litre per second. Only the most vulnerable tanks were to be lined.

Better days: six Concordes at Heathrow, Boxing Day 1986. Over the Christmas period it was possible to muster almost the entire fleet in one place. (British Airways)

The fuel leak patterns were studied when Concorde F-BVFB was flown to Istres near Marseille for ground testing. Accelerating on the runway to 175 knots, a leak (of an inert fluid) was simulated from an identical point to that in the Gonesse tragedy. Two other possible leak points were also assessed. Finding where the fuel went could reveal an ignition point and a flame stabilisation area – thought to be in the turbulent wake behind the undercarriage leg.

There were three likely sources of ignition – the reheat, an engine surge or an electric spark in the landing gear bay. The bay in question is just inboard of the engine nacelle and to the rear of the hole that had appeared in tank 5. From the distance between the fuel stain and the soot deposit on the runway, it was determined that ignition had occurred in less than a second after the tank was ruptured. All three ignition possibilities were tested at British Aerospace's Warton factory

near Blackpool.

A full-size mock-up of the left under-wing section, the side of the engine nacelle, and extended gear leg were built and set up on a concrete platform. The airflow for the flame tunnel came from the exhaust of Warton's high-speed tunnel. The flow required was 106m per second (206 knots).

Fuel was released from the 'Gonesse hole'. Streaming over the open undercarriage bay to the rear of the wing, the fuel was lit by gas burners simulating the reheat. The fuel ignited, but the flames were unable to advance up the fuel stream travelling at 106m per second. The advance rate was less than 10m per second. This ruled out reheat as a likely source of the ignition. The French investigators believed that the fire might have advanced in the slower moving air of the boundary layer (1mm thick) or through the various engine ducts. Neither theory proved likely.

To test whether the fuel leak was ignited by an engine surge, a 70-millisecond explosion was detonated and projected forward from the intake. A surge from the auxiliary intake of number 2 engine did ignite a fire that moved forward to the undercarriage bay. This cause was ruled out, however, since the surge occurred after the fire had started; engines 1 and 2 then surged again, probably due to the aircraft's rotation changing the angle of attack. This change of airflow allowed hot gas to be ingested by the engine through the auxiliary intake.

For the third test, a spark was generated in the undercarriage bay at the point where the brake cooling fan cable ran. On this occasion, a fire started in less than a second. It became stabilised in the eddies in the wake of the undercarriage leg and side stay. The flame pattern closely resembled the photograph of Concorde on fire, much to the distress of some observers.

Before the crash the crew had tried several times to retract the undercarriage. The final report, published in January 2002, suggests that the door of the left wheel bay had failed to open. This has to happen for the undercarriage raising sequence to begin. The door could have been damaged by the fire or debris, but unfortunately after the impact the evidence was destroyed. The hydraulic power for operating the undercarriage is from the 'green' system. Engines 1 and 2 generate

this system's pressure. No evidence exists to suggest that 'green' failed, until engine 1 ran down.

If the undercarriage could have been retracted, the fire might have put itself out. But survival would have depended on how much damage had been done to the fuselage – which may have already been breached – and whether the number 1 engine could have been kept going.

A jet engine surge is a momentary reversal of flow through the engine, not dissimilar to a backfire on a car. The phenomenon is measured in milliseconds, and sometimes a flame can be seen in the engine intake. A surge can be caused by the engine demanding a greater airflow than is being supplied, and vice versa. Internal damage and foreign object ingestion are other causes of surge. The investigators wanted to study engine surges caused by the ingestion of neat fuel or of hot gases.

When Concorde went into service there were two invitations: to 'fly the flag, fly the future' and to 'fly Concorde and arrive in better shape'. The shape became an icon and Concorde, through the changes of BA livery, kept elements of the Union flag. (© John

M.Dibbs)

Accordingly, at Shoeburyness near the Thames estuary, an Olympus engine was mounted on a rig (which had lain idle for 25 years) fitted with a simple air intake. The tests proved that the engine performed as per the evidence from the Gonesse tragedy. Following a rupture in a lined tank, there is an emission of an initial 'slug' of fuel. This was represented by accelerating the flow to 100 litres per second, at a rate of 30 litres per second per second. The engine surged but recovered and coped well with the steady leak rate.

THE NEAR ZERO GROWTH TYRE

Early in 2001, the team working on Concorde's return to service were told that Michelin was putting the finishing touches to a tyre that promised to meet the most stringent requirements. The new tyre was almost impossible to burst, but should it do so the debris would be small enough not to be a threat to the fuel tanks above. It was called the Near Zero Growth (NZG) tyre, and was a development of the company's radial ply tyre.

Michelin had been making radial ply tyres for road vehicles since 1946. In 1981 the Mirage III became the first aircraft to be fitted with radial tyres. The NZG tyre is an evolution of the radial tyre, and the tyre for Concorde is reinforced with Kevlar. Its advantage is that it does not expand significantly with inflation and centrifugal force. The outer surface of the tread is not under tension. This makes it less vulnerable to foreign object damage – it is easier to cut an elastic band when it is being stretched than when it is not. Furthermore, the tyre is lighter than a reinforced cross-ply tyre. To prove these claims, the new tyre was extensively tested.

Before trials on the actual aircraft, laboratory tests were carried out in the Michelin test centre and at the Centre d'Essais Aéronautique (CEAT) in Toulouse. Tyres were subjected to extreme conditions laid down by the aircraft manufacturer.

There was an important point to establish – could the tyre run over a similar strip of metal and continue to perform normally? Two tests were devised, one a low-speed test and the other high-speed. The NZG tyre

performed better than expected throughout.

Once, when the original cross-ply tyre was tested on a dynamometer, it burst and damaged the test equipment so badly that it took a week to rebuild. In contrast, the NZG tyre survived, cut, but inflated. In the end, only the Michelin NZG met the requirements of the damage resistance specification.

This was almost too good to be true. In case it was, BA kept up the momentum on fitting the tank liners and reinforcing the electrical power cable in the undercarriage bays. The tyre, the company said, could be seen as a bonus. Once the tyre had fulfilled its promise, it became an airworthiness requirement.

RETURN TO SERVICE

On 17 July 2001 a BA Concorde under the command of Captain Mike Bannister, accompanied by Jock Reid, CAA Chief Test Pilot, prepared to take off at Heathrow for a test flight over the Atlantic. Members of the world's press were perched on a scaffold near the runway, reminiscent of Concorde's first commercial service over 25 years before. An ordinary subsonic aircraft took off. Then it was Concorde's turn, but there was a delay. Had some irritating gremlin lit a warning light? The reason soon became clear – the runway was being inspected for foreign objects. After the yellow inspection truck had left the runway, a distinctive roar could be heard coming from the threshold of 09R. Then that familiar shape was in the sky, reheats burning, undercarriage retracting, right turn commencing and the press applauding.

There were three main reasons for the flight. The first was to measure the unusable fuel remaining, held between the Kevlar and the lower skin. Second, it was to find out whether the liners had affected the temperature of the lower wing surface, normally kept evenly warm by fuel convection. Third, it was to monitor all the systems to see whether anything had suffered during the year's grounding. The plan was to fly on the normal Atlantic track, then at 20 degrees west turn north towards Iceland. Here, at about 55,000ft, they would find the relatively warm air (-50°C [-58°F] and warmer). The more northerly the latitude, at high altitude, the warmer is the atmosphere. At such temperatures the

'stagnation' temperature limits Concorde's maximum speed, no more than 127°C (261°F) on the nose. Using the readings from thermocouples fitted in the fuel tanks, the engineers would assess whether the circulation had been jeopardised.

'E IS FOR ÉCOSSE'

On 7 November 2001, Lord Marshall, the Chairman of BA, his Chief Executive Rod Eddington, and BA guests, boarded G-BOAF for the first trip to New York since 15 August 2000. Valerie Grove of *The Times* was among the guests. She reported that Tony Benn was there to see them off. Benn told how he had fought for Concorde when the Treasury wanted to cancel it. He had also been on the test flight in 1970 equipped with a parachute. Then, with customary mischievousness, he told what he had said about the final 'e' of Concorde.

'E is for entente cordiale, E is for England.'

'But parts of it are made in Scotland,' had come the reply.

'Well E is for Écosse,' said Benn, looking thoroughly pleased with himself.

Concorde G-BOAF landed 3½ hours later at RAF Brize Norton in Oxfordshire. The world's press was there, and the low cloud, heavy rain and cold (for July) could not dampen the spirits. 'Concorde is back where she belongs, Mach 2 and 60,000ft,' announced a smiling Bannister. The flight had proved everything that it had set out to. On 6 September 2001 the Certificate of Airworthiness was reinstated.

Then came the 'dress rehearsals', with Concorde G-BOAF carrying 100 BA staff on a trip out to the mid-Atlantic and back, partly by way of reward for their work. The flight was an overwhelming success. In a matter of weeks, once three aircraft had been modified, services to New York would recommence. The date was 11 September 2001, and while the BA team were disembarking, news came through about the destruction of the World Trade Center and attack on the Pentagon. Would anybody want to fly now?

Concorde's many modifications may have cost £17 million, but the aircraft's return was due to the dedication and enthusiasm of the engineers, the pilots and the management of the two airlines. Would any other fleet of 12 aircraft with 25 years of service behind them have engendered such loyalty? With the exception of the Spitfire, it is difficult

to think of another aircraft that has excited the imagination so much.

This publicity photograph of four Concordes flying in formation was taken on Christmas Eve 1985. (British Airways)

Post-September 11, New Yorkers wanted to get back to normal as quickly as possible. On 7 November 2001, Mayor Rudolph Giuliani came to JFK airport to congratulate those whose hard work had restored Concorde to service. In so doing he praised the two airlines, as Valerie Grove reported in *The Times*:

> Sir David Frost, Concorde's most frequent traveller, sat at the back of the aircraft, having fallen into a light, refreshing doze. He woke in time to meet the outgoing Mayor of New York, Rudolph Giuliani, who boarded Concorde to welcome us all 'to New York City, the capital of the world,' adding:
> 'Do me a favour. Spend a lot of money.'
> He was addressing the right audience, as the flight was packed with captains of industry, chaps from Schroders and Allied Domecq and RM Rothschild. Dr Neville Bain, of Hogg Robinson, chairman of Consignia, professed himself thrilled to be back on Concorde, which gets him to New York for a late

breakfast meeting and back home to London the same night. 'I'm no use at video conferencing, it's not the same,' he said. 'I need to eyeball people, and touch them on the elbow.' Also, you do not get Krug and caviar in a video conference.

As he spoke, the Air France and BA Concordes were parked nose to nose, a re-enactment of their pose at Washington on their first arrival in the United States in May 1976.

THE END OF THE CONCORDE ERA

In March 1984, Sir Frank Whittle was guest speaker at the Concorde Dining Society's annual event, held in the RAF Club, Piccadilly, London. He recalled his aspiration that a jet-propelled aircraft 'might carry mail across the Atlantic at 500mph.' In the 1930s this was regarded as crazily optimistic. As for being able to cross the ocean at 1,350mph in a 100 seat passenger aircraft, he said, such a suggestion 'would have had me locked up'.

On 24 October 2003, after 27 years, the sun set on the first era of 1,350mph supersonic passenger flight. There is no successor in view and some contend that there never will be. I am not amongst them. The Concorde fleet still had (and indeed has) many 'reference flight cycles' available for use. These could have been translated into five or more years of service.

Indeed, following the tragedy at Gonesse, BA spent some £15 million on the modifications required to return all seven of its Concordes to flight and budgeted £14 million for the Sir Terence Conran Concorde cabin refurbishment, the 'interim' version of which was being fitted during Concorde's sabbatical. In the event, only five were modified for a return to service and Air France paid proportionately less to modify four aircraft, choosing not to refurbish its cabins. Clearly, with well over £30 million being spent or budgeted for, at that stage no one thought that only two years of commercial service would remain.

On 10 April 2003, Air France announced that its Concorde fleet would, on 31 May, be withdrawn from service. BA would withdraw Concorde by 31 October 2003. According to Captain Mike Bannister, Chief Concorde Pilot BA, it was 'the right decision, taken at the right

time'. The passenger-loads of both airlines were way below the pre-July 2000 figures. In particular Air France was suffering from an unofficial US boycott because of France's unco-operative stance over Iraq. On top of the knock-on effect that the conflict was having on air travel, the troubles faced by Enron, Worldcom and Arthur Andersen made it hard for business people to justify profligate spending on apparent luxuries like supersonic air travel. Perhaps to the joy of the company accountants, travel expenses diminished and, with interactive in-flight entertainment to alleviate the subsonic tedium, Concorde travel was no longer a corporate necessity.

WHAT WENT WRONG?

Before the accident at Gonesse it was said that the new BA Engineering Director, Alan McDonald, was not as enthusiastic as his predecessors had been in continuing with Concorde. He had been concerned about the disproportionate man-hour costs, five or six times as much for a Concorde flying hour compared to that, for instance, of a Boeing 747 – in spite of Concorde flying twice the miles per hour of a subsonic aircraft. Furthermore, new aircraft engineers were reluctant to become qualified on Concorde with its 'analogue' avionics.

In June 2000, a month before the Paris accident, it became apparent that the BA Concorde Major Checks would overlap one another. A 'Major' consists of a thorough service and testing of all systems and takes several months. Either the flying programme would have to be reduced or extra resources allocated to engineering. BA decided to stop charter flights.

When Concorde returned to service in November 2001, only the single daily New York flights and the once weekly Barbados flight were resurrected. At first the London to New York service departed at 10.30am, whilst the return schedule varied according to the number of serviceable Concordes available. With an aircraft available to 'night stop' in New York, the earlier and preferred service to London could be achieved. It was difficult to understand why the maintenance resource was inadequate in this respect; after all there were five modified Concordes, a number with which much more could have been done. For

the last few months of operation the 10.30am departure to New York from London was changed to 6.30pm – 'to suit the US market'. Soon it became obvious that aircraft 'AA' and 'AB' would not be modified with the Kevlar tank liners and would never fly again.

TECHNICAL INCIDENTS

Sadly, the Paris accident proved that Concorde was not immune from serious mishap. Following one or two technical problems, or as declared by the media 'safety scares', *The Sunday Times* reported, on 15 December 2002, that 'The Jet Set gets nervous of flying Concorde.' BA explained that the low (50%) load factors were due to the economic downturn, but the cost of the Concorde tickets appeared prohibitive to many, especially with the media reporting Concorde's every hiccup so gleefully. 'How can the Concorde fare be justified when pieces of rudder keep tearing off?' the media demanded.

'Concorde has two rudders, each capable of coping on its own,' was the reply.

'Is Concorde getting old?' the media persisted.

The Red Arrows formate on Concorde as they approach Heathrow for the airport's 50th anniversary flypast. (John Dibbs/aviation-images.com)

'Concorde is old in years but not in hours of use. Technologically Concorde is still way ahead of anything else,' came the defence. Yet, despite the number of people coming out in support of Concorde, they could not excuse a series of events that at best looked untidy and at worst heralded future failures; such as rudder delaminations.

The first rudder delamination happened to a BA Concorde during a round the world charter flight in 1989. The problem occurred when the rudder's aluminium alloy skin surface separated from the honeycomb internal metallic structure. After this incident it became apparent that new rudders were needed, and new rudder jigs were constructed from which replacement rudders were manufactured. The problem appeared to have been solved. Then, in November 2002, G-BOAE lost a portion of a new lower rudder. The remedy needed remedying. In February 2003, at the same age in hours of flight as BA's first incident, an Air

France Concorde experienced a similar problem and in early May 2003, Air France was to lose part of one more rudder, but by that time Concorde's fate had been sealed.

There were other incidents dismissible as 'teething' problems when the aircraft were new; but more difficult to justify after nearly 30 years' service. In April 2002, the British Chancellor of the Exchequer Gordon Brown flew on Concorde to the US for the G7 summit. En route G-BOAD suffered an engine surge. In consequence the aircraft was delayed by 30 minutes; an event considered newsworthy because of the high profile of both the passengers and the aircraft and, consequently, another nail in Concorde's coffin.

As already suggested, any such incident occurring post-Gonesse attracted disproportionate press scrutiny. Airbus (formerly British Aerospace and Aerospatiale) had worked hard helping Air France and BA return Concorde to service and once Airbus' high-profile offspring had been restored to health, Airbus could again proudly admit to its parenthood. To endure another major incident, or even a series of minor ones, threatened Airbus' reputation. Furthermore, Airbus wanted to concentrate on the launch of the 550-seat A380. Nothing should undermine its new position as the world's number one civil aircraft constructor.

PASSENGER NUMBERS AND PROFITABILITY

Meanwhile Boeing, having opted out of the Sonic Cruiser project, was extolling the virtue of smaller, cleaner aircraft flying point-to-point.* This would be a better use of existing resources and avoid forcing everyone through a hub like Heathrow. Adam Brown, Vice-President of Airbus noted, in a radio interview, that the A380 would be the most fuel efficient airliner of all with the lowest levels of harmful emissions. According to BAA (British Airports Authority) there could be an increase in Heathrow's passenger volume of up to 10 million per year (about 20%) without any additional investment in infrastructure through the use of such super-jumbos.

Concorde is all about speed and status. Since 1988, according to Jock Lowe, there had been a gradual decline in the numbers of clientele. To

address this there had been a suggestion to rearrange the interior, having an extra luxurious front cabin while keeping the standard layout in the rear; a 'super-first' class and a 'super-club' class. With Concorde still profitable there was no serious pressure for change, so the modification was not made. Post-November 2001 this kind of modification might have helped. Had the Concorde operation been re-established as a 'division' or 'profit centre', then such changes would have been easier to implement.

Concorde served two groups, the 'premium' customers – top business people, sports and film stars – and those interested in experiencing Concorde. Each group encouraged the other. Following the return to service, charter flights could have been used as a way of rehabilitating Concorde and re-establishing her reputation. When Concorde's withdrawal was announced it became apparent that her reputation was largely still intact, at least among the general public – take-up of tickets soared. Clearly the market was there. Unfortunately it took a 'must-end-by-date' to realise it and by then it was too late, especially for Air France.

Concorde G-BOAF in flight. (© John M. Dibbs)

FAREWELL TO CONCORDE

Since November 2001, if not well before, the Air France Concorde operation had not been profitable. In early 2003, with privatisation in view, loss-making divisions of the airline would have to go. Then on 19 February 2003 Air France suffered another worrying incident.

A Concorde en route to Paris from New York experienced a failure, which demanded the shut down of an engine. The crew applied the appropriate drill requiring the closure of the 'HP' (High Pressure) fuel cock; but not of the 'LP' (Low Pressure) cock allowing fuel to circulate for system cooling purposes. There was, however, a fractured pipe downstream of the 'LP' but upstream of the 'HP' cock. Mercifully, the crew spotted the fuel loss in time and stemmed it by the closure of the 'LP' cock. There was no risk of a fire. They turned back to Halifax where they landed with minimal fuel. To prevent a repeat occurrence

the drill was changed: the 'LP' cock would always be closed in similar circumstances.

With Concorde attracting bad publicity and losing money at the same time, Air France could see no point in keeping the aircraft flying. It would cease operating Concorde and stop paying the 'support costs' (payable to Airbus, who held the Design Authority). As a result, BA would have to bear the full brunt of the support costs and if they were unable to, would be forced to end their Concorde operation. In 1962 the treaty between France and Britain to build Concorde forbade either country from withdrawing from the project unilaterally without paying its half of the total. In 1984 each country was deemed to be in balance with the other in respect of payments. In future there would be no obligatory payments between the two countries if one of them wished to stop.

Airbus, with its reputation on the line and a new aircraft imminent, was not prepared to maintain support of Concorde at the old price. BA was not prepared to pay the new increased cost alone. It seemed to many that Airbus was losing faith in Concorde yet Captain Les Brodie, BA Concorde Training Manager, spoke of the confidence the crews had in the airframe, systems and back-up systems. There was plenty of spare capacity built in. Having flown Concorde on test, where emergency systems are exercised, Brodie's declaration of faith is a telling one.

BA wanted a year or more in order to bid farewell to its flagship. Air France chose 31 May 2003, some seven weeks ahead. Airbus agreed to continue to support BA for only six months. The final day was to be 24 October 2003. Concorde would visit former destinations on specially organised flights and a Grand Finale would be arranged at Heathrow for the last day of operation. Thereafter, the Concordes that could fly would be flown to various museums, and those that could not, dismantled for haulage by surface. Once civil supersonic flight had become a finite commodity, all flights became overbooked. Was there no way that Concorde could be saved?

CONCORDE'S LAST HOPE

A group of BA Concorde crew attempted a rescue. They extolled

Concorde's virtues: its uniqueness, its power to inspire and, since the termination announcement, its earning capability. This 'Concorde Experience' market had the potential of lasting well over 18 months; it was a shame, they said, not to take advantage of it. The scheduled flights now resembled the former charter flights. As no flight deck visits were permitted whilst airborne (due to post '9/11' security measures), the crew offered to host visits to the cockpit after arrival, such was the dedication that Concorde inspired.

The group approached Rod Eddington, Chief Executive of BA. One of its proposals was to set up a Heritage Flight retaining an aircraft for special occasions – such as the Queen's Golden Jubilee flypast. It would, with no profit, have fended off the criticism BA was suffering for withdrawing Concorde. The termination costs however, some £80 million, would still have been payable. Airbus would not support this idea and it was dropped.

Concorde climbing at sunset, nose drooped. (Travel Pictures/Alamy Stock Photo)

It was thought that Airbus might be more malleable if both BA and Air France were involved, so the second option was to form an alliance with Air France and perhaps even include Rolls-Royce. Although some Air France Concorde pilots liked the idea, Air France Chairman Jean-Cyril Spinetta was not interested, so this option failed as well.

The next hope was to operate Concorde in a wholly owned BA subsidiary company. This idea initially gained Rod Eddington's support but Airbus appeared intransigently set against supporting Concorde and it is doubtful whether the BA Board would have approved it. For the final option, that of a management buy-out, there was no chance of success. Even had Airbus approved, BA would not have done so, as it would have received less than from the other plans.

The company responsible for performing the product support function must hold the Design Authority (DA) of that product. In this case Airbus holds the DA of Concorde. If Airbus wished to withdraw support, could the DA be held by another organisation? In essence the answer is yes; but Airbus would still have felt liable should there have been an accident attributable to a design error. Furthermore, Airbus would not have wanted to lose control of its intellectual property. The air intake control system, for example, was still regarded as being commercially sensitive. To whom did the intellectual property belong anyway? It could be argued that it was the taxpayers', or at any rate belonged to the governments of France and the UK. There were plenty of companies capable of holding the DA – Marshall Aerospace at Cambridge for one and BAE Systems for another (although BAE Systems would have found its loyalty divided since it itself is part of Airbus). It might even be possible for BA to hold the DA; after all, in early 2004 BA had as much experience of Concorde as any other organisation. The question was never resolved.

G-BOAF above the clouds, photographed in what was to be the BA Concordes' final livery. (British Airways)

Concorde, whose slender delta and subtly cambered wings drew admiration from every angle, was about to be grounded for good. It must have been agonising for BA when arguably its greatest symbol was being forced out of the skies. The one aircraft that distinguished BA from all of the rest, apart from Air France, was to be removed. The 'exeunt' would need careful handling. To end supersonic services was one thing, but to botch up the overture to, and the Grand Finale itself would be truly unforgivable and damaging to BA.

BA AND VIRGIN ATLANTIC

Sir Richard Branson, head of Virgin Atlantic, had always been an admirer of Concorde. He had in the past approached Air France with a view of obtaining at least three aircraft – about the minimum required to support a transatlantic

service. Now he saw his opportunity. He noted that some of the BA fleet had been acquired for the nominal sum of £1 sterling. Surely he as a British taxpayer had some say in their disposal? (He conveniently overlooked the £16 million paid by BA in the 1984 settlement and subsequent investment in modifications and refurbishment.) Concorde was a great British success story – if BA was unable to fly it, then Virgin would, and at reduced operating cost too. He would approach Patricia Hewitt, Labour MP and Trade and Industry Secretary, to gain financial backing. The Government, remembering its predecessors' involvement, declined. Acknowledging that BA would have felt unhappy to see Concorde decked out in Virgin colours, Sir Richard suggested that the BA logo could remain on his newly acquired aircraft, on one side, with Virgin's on the other.

On 30 April 2003, Sir Richard appeared as a guest on the Richard and Judy television show on Channel 4. On the telephone was Lord Marshall, Chairman of BA, who stated that Airbus would no longer support Concorde whoever the operator was. Sir Richard claimed that BA had instructed Airbus to say this, which Lord Marshall denied. When the results of a poll suggesting that 97% of the British population supported Sir Richard's bid were cited, Lord Marshall pointed out that if BA were to offer to keep Concorde flying it too would receive overwhelming support.

Sir Richard was not to be stopped so lightly. Uden Associates arranged for Sir Richard to narrate a Channel 5 documentary entitled 'The Concorde Story'. Sir Richard was full of praise for Concorde but also made a smiling reference to his own airline. On another occasion he was seen with an inflatable model of Concorde tucked under his arm, stating that as BA could not keep it up, he should be allowed a try. In the event, his bluff was never called.

GRAND FINALE

For Concorde's last day of commercial operation, 24 October 2003, BA had planned a spectacular celebration. Many of the world's press and television media congregated at Heathrow for this final Concorde photo opportunity. A grandstand was set up overlooking the northerly runway 09L/27R and a 'media stand' was constructed with a view of the final parking area. Three Concordes, landing in succession, were due to arrive at 4.00pm from Edinburgh, Heathrow (via the Bay of Biscay) and New York. All five modified Concordes were serviceable, so in the event of an engineering problem there was plenty of cover. On the first day of commercial operations, 21 January 1976, two Concordes had behaved immaculately, departing from Paris and London simultaneously. Would the same be true on the last?

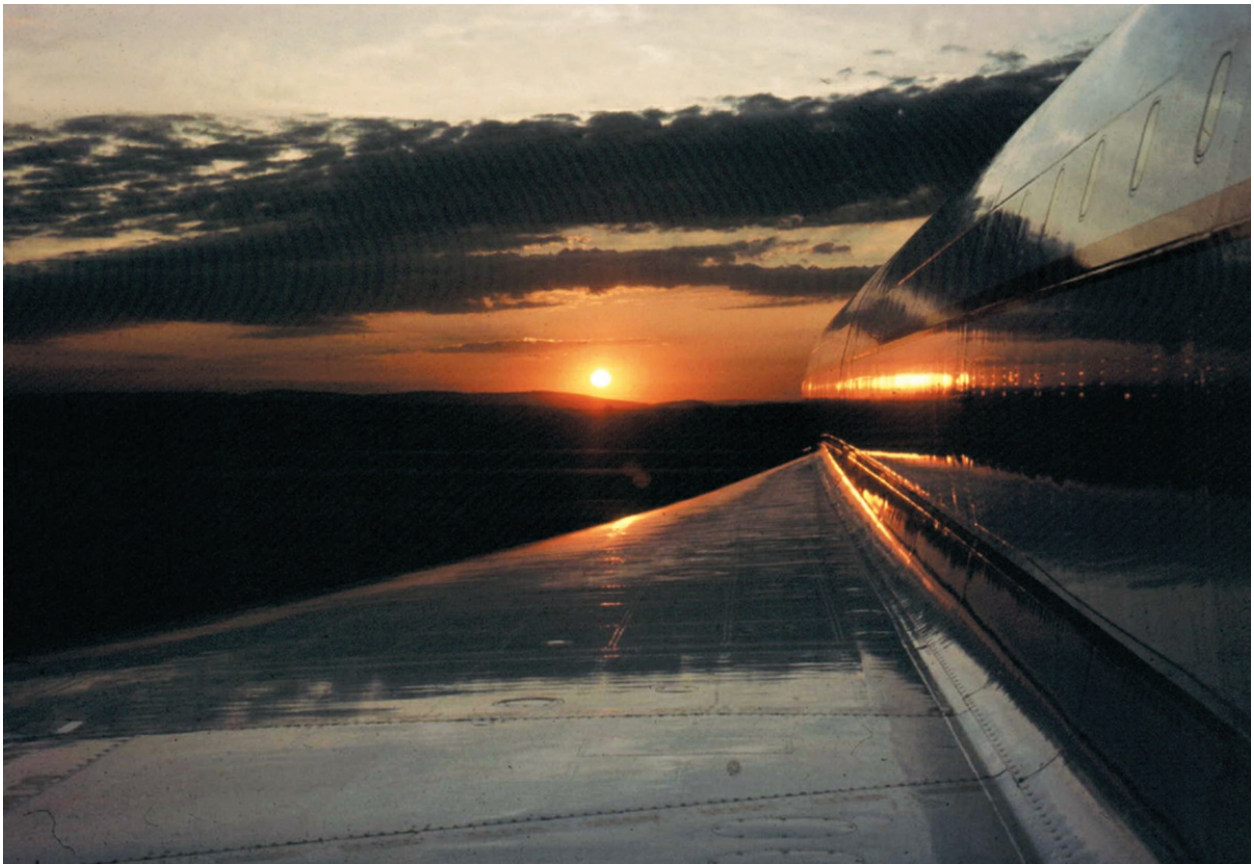
In the morning of 24 October 2003 Captain Andy Baillie had flown G-BOAE to Edinburgh with a supersonic excursion out over the North Sea. Captain Les Brodie took over for the return to London. Both flights were full of BA staff and excited competition winners. In the afternoon the second Concorde, G-BOAF, captained by Paul Douglas, departed London for a supersonic flight around the Bay of Biscay. Amongst the passengers were Concorde alumni – Captains Brian Walpole, Jock Lowe and David Rowland. Also aboard was John Cochrane, the co-pilot on Concorde prototype 002's first flight in 1969. At midday UK time (dawn Eastern Standard Time) the final transatlantic Concorde service departed New York with Captain Mike Bannister at the helm. This flight was scheduled to be the last Concorde to land at Heathrow. For those watching and waiting, the weather was fine but, due to a brisk north-westerly wind, cold.

BBC presenter John Sopel and I were installed in the warmth of a temporary studio rigged on the media stand overlooking parked Concorde G-BOAC, which had visited Cardiff the previous day. Also waiting was former Concorde Captain John Hutchinson, scheduled to talk about the triple arrival in the afternoon. I asked him how he was and how he felt about the demise of Concorde. 'I am very well,' he replied, 'but I am sad, very sad. Personally I don't feel that BA should be giving up the aeroplane at all. It has got plenty of life left in it.' It was time for BA002 to depart from New York and my moment to commentate.

A monitor showed that Concorde BA002 had left BA's terminal at New York. The fire brigade arranged their traditional farewell – a water arch under which G-BOAG taxied. I previewed the take-off sequence hoping I had guessed the correct runway – 31L, I had. Soon Concorde was rolling along the same runway from which she had first taken off in October 1977.

For the last time Concorde G-BOAG performed the same manoeuvre. As she climbed, the reheats were switched off on cue. A helicopter (one of six), hovering to the north-east of Jamaica Bay, captured the whole sequence as Concorde continued her turn, climbing up and away towards the Atlantic and Great Britain. Air Traffic Control bade her farewell for the last time.

Some three-and-a-quarter hours later Concorde had crossed the Atlantic and was flying towards Ockham in Surrey at Flight Level 80 (about 8,000ft). Viewers of BBC2 heard the conversation between Senior Engineer Roger Woodcock, aboard BA002, updating Adrian Dolan of Air Traffic Control (ATC) in the Heathrow Control Tower with G-BOAG's latest position. Roger announced the revised route 'AG' would take; north over Heathrow to Hillingdon, east to the Thames Barrier, descending to 2,500ft, right-hand base leg to intercept the extended centre line of runway 27R, Greenwich, Canary Wharf, over the City with BA's London Eye on the left, over The Mall and Buckingham Palace and on to Heathrow; ETA 4.08pm local time.



Looking west over a delta wing. When Concorde was operating it was possible to see the sun rise from the west. (Author Collection)

Adrian Dolan said that it had been a pleasure looking after Concorde for the last 30 years and that ATC's job without Concorde was 'changed for ever'. Roger Woodcock thanked ATC for its help and

added how much the crews appreciated returning home to the professionalism of the UK's ATC.

On duty in the control tower was Ivor Sims. In 1976, Ivor had given take-off clearance to the very first commercial BA Concorde flight to Bahrain. Today he would be clearing each Concorde to land.

On the airport roads, vehicles cluttered the verges and central reservations to marvel at the spectacle. Concorde had caught the imagination of millions and the BAA was not going to interrupt their homage. When Concorde was new the traffic jams were in protest, now they were in praise.

TOUCHDOWN AT HEATHROW

Back at Heathrow, just after 4.00pm, approaching from the east and having flown from Edinburgh, the first of the three Concordes could be seen. With an attitude of 11 degrees and undercarriage extended, G-BOAE was coming home. For a moment that familiar noise (never an irritant to the devotees of Concorde) reverberated. Too soon it would be confined to historic recordings. The specially erected grandstand on the north side was now packed with invitees and fans waving their Union flags.

Prior to the first touchdown a silence descended on the crowd. The gusting north-westerly wind nearly caused Captain Brodie in 'AE' to 'go-around'. With a sudden loss of headwind and with only feet under the aircraft, Brodie eased back on the control column to avoid arriving too firmly and brushed the runway, before smoothly touching down and lowering the nose wheel – a neatly handled cross wind landing complicated by wind shear. Two minutes and 21 seconds later Paul Douglas landed smoothly in 'AF', decelerated and cancelled reverse thrust before vacating the runway and following 'AE'.

The cameras now turned towards the third and final aircraft, G-BOAG, Flight BA002 from New York (call sign 'Speedbird Concorde zero zero two') approaching from the east. The studio discussion at that moment concerned the nose and visor and what it did for visibility from the flight deck. The subsequent question 'Why weren't more Concordes built?' remained unanswered for, just at that moment, a picture of 'AG'

flying away from the camera caused John Sopel to say, 'I want to pause us slightly now, as this is going to be the final Concorde that people are going to see coming in to land at Heathrow. This is it. This is the end of the era.'

Those watching beside the tarmac or on television marvelled at this aeronautical art form – this wing shape capable of spanning over 1,100 knots without the assistance of flaps and slats. As 'AG' slowed for the approach, the angle of attack increased to generate more vortex lift. Now the extra drag demanded an increase of power; to restore vision ahead the nose was lowered. As the runway approached, the gear was extended, 'down, four greens,' confirmed the crew. This finely honed routine was being played out, with passengers into Heathrow, for the last time. Would that the world had loved the craft at the beginning. 'One hundred feet,' called the engineer, 'fifty,' the autothrottles were disconnected. 'Forty, thirty, twenty, fifteen,' the throttles were closed. The tendency of the slender delta to pitch down (reduce its angle with the horizontal) due to thrust reduction and ground effect was countered with 'up' elevon reducing the rate of descent. The wind was from the right, so the drift was removed with left rudder while the wings were kept level with elevon. Bannister's touchdown was perfect; but the applause was as much for 27 years of Concorde as for the landing.

G-BOAF being pushed-back into the Brabazon hangar by a tug after the last ever flight of a Concorde. (Mark Wagner/aviation-images.com)

All three Concordes vacated 27R and taxied along the 'outer' taxiway until they were facing east in the vicinity of the 'November' parking stands. With the grandstand to their left and ground staff to their right, all three aircraft simultaneously performed the Concorde bow – the sedate lowering and raising of the nose and visor.

The Edinburgh and Biscay Concordes then proceeded on a very slow taxi of honour around Heathrow's stands as hundreds of enthusiastic airport employees clapped and waved. Before the Compass Centre there was another bow. Meanwhile 'AG' was linked to a tug with a ground power unit and towed to the engineering base. Here a red carpet welcome was waiting. Captain Mike Bannister and Senior First Officer Jonathan Napier, leaning out of their 'DV' (Direct Vision, i.e. openable) windows, waved Union Jacks. Mike had suffered a soaking from a water arch when the chart holder prevented the quick closure of his DV

window, but his bonhomie was undampened. The guests assembled in a hangar housing G-BOAD cheered the arriving spectacle. As 'AG' drew up alongside 'AC', steps were manoeuvred into position and a dispatcher knocked on the passenger door. Eventually (reluctantly?) the door opened from the inside. Concorde had finally come home, safely delivering the last 100 of 2.5 million passengers.

First to appear from 'AG' was BA Chairman Lord Marshall, who descended the steps looking fit and fresh after his Atlantic crossing. He was greeted by his Chief Executive, Rod Eddington, clad in a yellow 'dayglo' tabard to comply with airport anti-collision regulations. Next off the plane was Joan Collins. Sir David Frost followed, only to be waylaid by a microphone on the end of a long pole, despite the 'cordon sanitaire' between the red carpet and the media. 'The only aircraft that lets you be in two places at the same time,' he had said of Concorde. Model Christie Brinkley had her photograph taken under the nose of 'AG' while Jodie Kidd chatted with interviewers across the divide. The Duke of Kent, who had been a passenger on the first BA supersonic flight to Bahrain, walked briskly along the red carpet before turning to watch Mike Bannister extol the 'one big family' that had made Concorde work. 'It's a celebration,' Mike added as he moved on to the next microphone.

FINAL FLIGHT

A few weeks later, on 26 November 2003, I parked my car on the central reservation of the A3044 directly under the departure path of Heathrow's 27R. There had been heavy rain but that had not discouraged the thousands of people congregating to witness the final take-off of this extraordinary flying machine. Would the crowds have turned out to watch the last departure of a 747?

Sadly there would be no Concorde flying on 17 December 2003 just three weeks later for the 100th anniversary of powered flight. On that day Orville Wright had flown a distance two-thirds the length of Concorde, taking the same time as Concorde would take to cover four and a half miles. Yet the aircraft were not entirely dissimilar. One particular feature of the Wrights' inventiveness was applied to

Concorde's flying controls: the Flyer's rudder application was mechanically coordinated with lateral control inputs. Using auto-stabilisation in 'electrical' signalling to the flying controls Concorde did just the same. Left elevon would apply left rudder and vice-versa.

Just as the Wrights had settled who would become the world's first pilot – by tossing a coin – so it was resolved who would be the last to land Concorde. Paul Douglas flipped the coin, Les Brodie called 'heads' and won. As he put it, 'It was the Queen who decided.' Paul's compensation was to handle, from the right-hand seat, the last Concorde take-off from Heathrow.

'Here she comes,' someone shouted, heads turned, hands clapped and people cheered. Elegant, purposeful, beautiful, businesslike, sculpted, fast – the hyperboles raced around the mind. The undercarriage retracted, the reheats were switched off and Concorde 216 G-BOAF (the last to be built) was on her way.

After the Channel Islands, Concorde turned north to Compton before turning west to fly over Filton towards the coastline. Thereafter, south-west to Weston-Super-Mare before turning to Bristol International (Lulsgate). From there to the Clifton Suspension Bridge, turning north over the Downs then east towards Marshfield in a 'tear-drop', making a wide left turn to intercept, in the vicinity of Tormarton, the extended centre line of runway 27 at Filton.

The flight crew had previously taken a helicopter ride around the Bristol area so that they could locate the various landmarks. On 26 November, the famous photograph of Concorde 216 over the Clifton Suspension Bridge was taken from that same helicopter hovering at 3,000ft, 1,000ft above Concorde (see here). Many devotees on the Downs had found time to stop and stare. Bristolians built this Concorde, some spent the bulk of their careers caring for her; a project that had shrunk the world for 27 years. Someone had had the wisdom to allocate the last of the Concorde line to Filton.

Les Brodie's wife and daughter were watching his landing from the control tower at Filton. The wind was gusting from the south-west (240°/13). The runway is twice the width of the standard runway, 90m versus 45m. The pilot, therefore, is under the illusion of being lower than he is. Result: high flare, long float, deep landing. With a tail wind

the float is longer and there is a hump which obscures the proximity of the end of the runway, which then appears very quickly. The author is writing from first-hand experience. Fortunately the carbon fibre brakes were very effective on that occasion. 'Fifty, forty, twenty, fifteen.' It was a perfect landing. Guests of Airbus at Filton, including the Duke of York, applauded the event.

REFLECTIONS

G-BOAF was towed to the Brabazon hanger for decommissioning. This involved the removal of all fluids, the battery, inflatable escape slides and anything that could be dangerous to visitors. The facility to power the aircraft with a ground-power unit was deactivated. There are plans at Filton to have a proper display hangar for 216.

Concorde G-BOAD aboard a barge in New York harbour, en route to the Intrepid Sea, Air & Space Museum where it is displayed, on loan from BA. (US Coast Guard)

By 2005 every Concorde except G-BOAB had arrived at its final place of exhibition and, although decommissioned, it would not be impossible to make some of them fit for flight again. Claude Freeman, BA Chief Concorde Ground Engineer, estimated that six months' work would be necessary to return one to flight. The Tu-144 flew again after several years of storage. If the Air Intake Control Units have been removed, hopefully they are safely stored. It is hard to believe that these early digital computers still represent leading edge technology.

'Three hundred and twenty thousand pounds, gone,' BANG – not the shock wave from a supersonic plane, but the staggering price paid for a Concorde nose cone. The date was 1 December 2003, the location Olympia, London and the occasion, Bonham's auction of Concorde spare parts that raised funds for the charity 'Get Kids Going'. Even a Machmeter fetched £28,000. A similar sale by Air France in Paris had also astonished cognoscenti with items fetching ten times their reserve price.

Was the Concorde project worthwhile? If it had been known on 29 November 1962 that only 14 supersonic airliners would enter service, the answer would surely have been no. At each stage of the project, however, the answer was yes. Concorde had served a generation and, what is more, justified herself. Sad though the end was to be, a planned celebration would sweeten the bitter pill; better a Grand Finale than an ill-defined fade out. Well done BA and Air France for having done justice to a remarkable project. The words on a BA poster summed up the end of the (first?) supersonic era: 'How did 27 years go so fast?'

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* Subsequently proved to be just one.

* The Sonic Cruiser was never built, being more of a design study about cruising at transonic speed. The cynics said it was designed to take the spotlight off the new Airbus A380.

THE AFTERMATH

G-BOAA was BA's first Concorde. It is now exhibited at the Museum of Flight, East Fortune. (© Gordon Barnes)

When Concorde services came rather suddenly to a halt in 2003, no one appeared to know where to exhibit the five Air France and eight British Airways Concordes. Many soon found homes in museums across the world, however, and have been attracting visitors ever since.

THE AIR FRANCE CONCORDES

Air France had completed its last service at the end of May 2003, and within a fortnight their aircraft were off. On 12 June 2003 Air France

Concorde 205 (F-BVFA) was flown to Washington for exhibition at the Steven F Udvar-Hazy Center – a companion part of the Smithsonian Air and Space Museum.

On 14 June 2003 Air France Concorde 213 (F-BTSD) was flown from Paris Charles de Gaulle to Le Bourget. 'SD' is now displayed alongside Concorde 001 at the Le Bourget Air and Space Museum.

On 24 June 2003 Air France Concorde 207 (F-BVFB) was flown from Paris Charles de Gaulle to Karlsruhe Baden-Baden. Here the aircraft was partially dismantled, then taken by barge and road to the Auto & Technik Museum Sinsheim, Baden-Wurtemberg, Germany. 'FB' was a gift from Air France to the museum, and in the handover Jean-Cyril Spinetta, the Chairman of Air France, paid homage to those who had died in Concorde Flight 4590 on 25 July 2000. 'FB' is now spectacularly displayed as if in flight in formation with a Tu-144. The interior of the aircraft is accessible to visitors in spite of the pitch attitude.

Two supersonic airliners are now displayed on the roof of the Sinsheim Auto & Technik Museum, Concorde F-BVFB and Tu-144 77112. (Stuart Pearce)

On 27 June 2003 Air France Concorde 209 (F-BVFC) was flown from Paris Charles de Gaulle to Toulouse. 30,000 Airbus employees lined the runway to watch the arrival. Concorde had re-established the status of the French aero industry which had been lost due to the Second World War, and now in the 21st century Airbus was vying with Boeing as a leading builder of civil airliners. Disembarking to a rapturous applause was André Turcat, the pilot of the first Concorde flight on 2 March 1969.

THE BRITISH AIRWAYS CONCORDES

The final flights of the BA Concordes had converged on Heathrow on 24 October 2003. With no storage space at the airport, the serviceability of the aircraft running out and the time limit of the pilots' qualification approaching, the flyable Concordes had to go ASAP. At that time only five of the seven were flyable, so those that could fly, did. One of those that could not left by barge and the final one (at the time of writing) is still at Heathrow.

Concorde 204 (G-BOAC) arrived at Manchester on 31 October 2003. 'AC' is now on display under cover in a purpose-built hangar. By the time the airline took delivery of 'AC', the airline had changed its name. BOAC and BEA had merged to become British Airways, and G-BOAC's registration lost its obvious significance. Nevertheless this Concorde is regarded as the flagship.

Concorde 214 (G-BOAG) arrived at Seattle on 5 November 2003 – the 45th anniversary of the first sitting of the STAC (Supersonic Transport Aircraft Committee) chaired by Morien Morgan (later Sir). 'AG' is on display at the Museum of Flight. Had Boeing chosen a delta instead of a swing wing design for the US SST, it might not have been cancelled, in which case there would have been many more Concordes and US SSTs flying. Had that been the case, how long would it have taken to make either SST sufficiently quiet?

Concorde 208 (G-BOAB) has remained at Heathrow. It had been hoped that 'AB' could be displayed at Terminal 5, but at the time of

writing no plan has been made. There has been a suggestion of dismantling it and reconstructing it at a site near the London Eye on the south bank of the Thames. However, this venue may be too close to the exhibit at Brooklands to allow public access – stipulated when 'DG' was taken on at Brooklands.

On 10 November 2003, Concorde 210 (G-BOAD) arrived at JFK New York. 'AD' was transported by barge to the west side of Manhattan Island to be a feature alongside the aircraft carrier USS *Intrepid*. The left-hand side of 'AD' displayed Singapore Airlines' livery for the short period that the route from Bahrain was extended 1979–1980.

Concorde 212 (G-BOAE) arrived at Barbados on 11 November 2003. 'AE' is on display and under cover at Grantley Adams airfield.

In April 2004, Concorde 206 (G-BOAA) was dismantled at Heathrow, taken by road to Isleworth and loaded on a barge. When the neap tides came, clearance under the Thames bridges was assured and 'AA' set sail for Scotland. Reconstructed at the East Fortune Museum, 'AA' is a major attraction.

Concorde 216 (G-BOAF) made the final landing of all the Concordes at Filton on 26 November 2003. The management in charge of exhibiting 'AF' had hoped that if 'DG' was kept, then Filton could show one without furnishings – displaying the innovative engineering which allowed for the expansion and contraction experienced during a supersonic flight – and the other fully furnished as the passengers would have found her.

Concorde 202 (G-BBDG) was offered to the Brooklands Museum Trust in October 2003. The aircraft would have to be cut up into sufficiently small pieces to satisfy road regulations. Now the visitor, seated in the front cabin of 'DG', can view a video of a flight narrated and acted out by Captain Mike Bannister from the flight deck of 'DG' itself. If the visitor is still wishing to get to grips with the Concorde technology, he or she can, for further fee, fly the simulator under the instruction of a former Concorde pilot.

Let us never forget that in spite of all its setbacks, Concorde proved to be a great inspiration to many. Even in 'museum mode' it attracts enormous adulation, and in 2006 was overwhelmingly voted Design

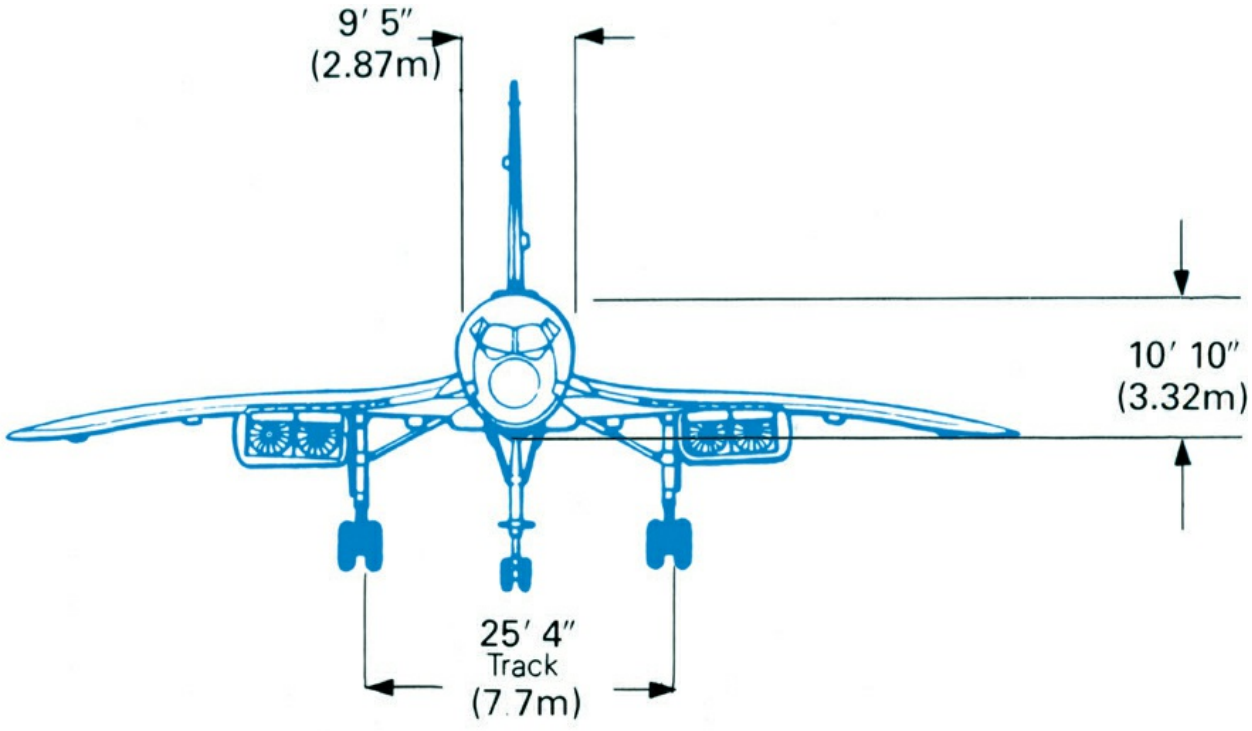
Icon of the 20th Century. Vive le Concorde.

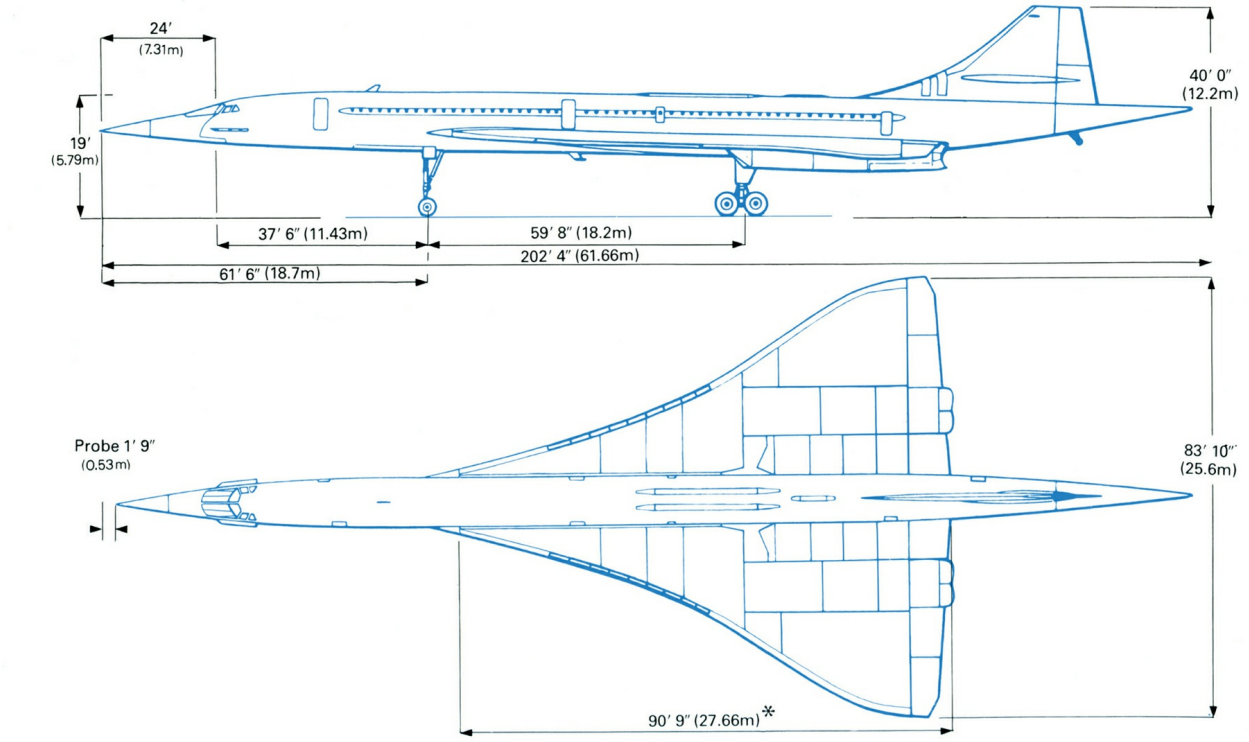
However stunning Concorde looks beneath her natural working environment – the sky – the vagaries of corrosion are better avoided. At Manchester Concorde G-BOAC is now housed in a hangar. (© Michael Derby)

APPENDICES

Max take-off weight	185,070kg (408,000lb)
Max landing weight	111,130kg (245,000lb)
Max weight without fuel	92,080kg (203,000lb)
Max payload (approx)	13,150kg (29,000lb)
Max number of passengers	128 (but BA Concordes were fitted with 100 passenger seats)
Max fuel at specific gravity 0.80 limited by volume	95,680kg (26,400 gallons)

CONCORDE – LEADING DIMENSIONS





CONCORDE – UTILISATION DETAILS

CONCORDES BUILT IN THE UNITED KINGDOM

Aircraft Registration	No.	1st Flights	Hours	Landings	Supersonic Flights	Reference Flights	Retired to
G-BSST	002	April 1969	836	438	196	—	Yeovilton
G-AXDN	101	December 1971	633	273	168	—	Duxford
G-BDDG	202	February 1974	1,435	—	633	—	Brooklands
G-BOAC	204	February 1975	22,260	7,729	6,760	6,890	Manchester
G-BOAA	206	November 1975	22,769	8,064	6,842	7,086	Edinburgh
G-BOAB	208	May 1976	22,297	7,810	6,688	6,974	Heathrow
G-BOAD	210	August 1976	23,397	8,406	7,010	7,294	New York
G-BOAE	212	March 1977	23,376	8,383	7,003	7,357	Barbados
G-BOAG*	214	April 1978	16,239	5,633	5,066	5,078	Seattle
G-BOAF**	216	April 1979	18,257	6,045	5,639	5,555	Filton
BA total			**148,595**	**52,070**	**45,008**		

Prototype: 002, Pre-production: 101, Production: 202–216, only 204–216 flown commercially.

* formerly G-BFKW, ** formerly G-BFKX

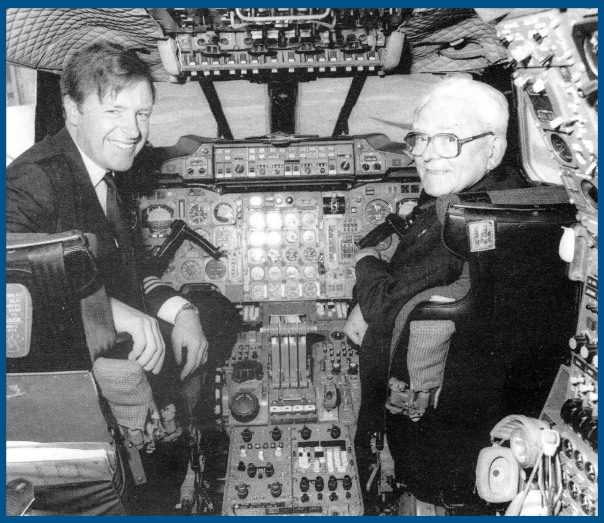
The rig at Farnborough achieved 20,000 equivalent supersonic cycles. Originally measured in supersonic cycles the new yardstick, for BA, became 'reference flights' which included a compensation for light take-off weights. However there was no finite limit to the life of the airframe.

CONCORDES BUILT IN FRANCE

Aircraft Registration	No.	1st flight	Hours	Landings	Supersonic Flights	Reference Flights	Retired to
F-WTSS	001	March 1969	812	397	249	—	Le Bourget
F-WTSA	102	January 1973	657	314	189	—	Orly
F-WTSB	201	December 1973	910	423	247	—	Toulouse
F-BTSC*	203	January 1975	11,989	4,481	3,978	—	Crashed
F-BVFA	205	October 1975	17,824	6,780	5,504	—	Washington
F-BVFB	207	March 1976	14,771	5,473	4,791	—	Sinsheim
F-BVFC	209	July 1976	14,322	4,358	4,200	—	Toulouse
F-BVFD	211	February 1977	5,814	1,929	1,807	—	Broken up
F-BTSD**	213	June 1978	12,974	5,135	3,672	—	Le Bourget
F-BVFF†	215	December 1978	12,421	4,259	3,734	—	CDG
AF total			**90,115**	**32,415**	**27,686**		

Prototype: 001, Pre-production: 102, Production: 201–215, only 203–215 flown commercially.
* formerly F-WTSC, ** formerly F-WJAM, † formerly F-WJAN

Christopher Orlebar began piloting Concorde in 1976. Dismayed at the criticism of the aircraft expressed in a 'Tomorrow's World' programme just as supersonic services were starting, he persuaded the BBC to make 'Faster Than the Sun' for the QED series (1982). This was followed by 'Jet Trail', which studied how the jet engine had revolutionised civil flight. He is pictured here with Sir Frank Whittle, inventor of the jet engine principle, on the flight deck of Concorde during filming in May 1984. (Author Collection)



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Front cover: G-BOAC in flight. (FlightGlobal)

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